Title:

ECOLOGY OF THE MIGRATION AND DISTRIBUTION OF THE ANCHOVY *Engraulis capensis* OFF NAMIBIA.

by

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ABSTRACT

This thesis investigates the patterns of distribution and migration of the adult and recruit shoals of anchovy Engraulis capensis off Namibia and the environmental factors most important to such distributions and migrations. It also examines anchovy feeding patterns.

The distributions of anchovy shoals in summer months were recorded during extensive, acoustic surveys along the whole Namibian coastline from November 1978 to March 1982. A purse-seine fishing vessel was used to identify the shoals detected. Winter surveys of selected parts of the coastal waters recorded shoal distribution and sampled the fish and environmental factors associated with the densest shoal groups. Shoal groups were followed for periods in excess of 24 hours and sampled at 4-hour intervals. Winter distribution, length and age composition were also obtained from the commercial fishery statistics. Stomach contents extracted from samples of anchovy shoals were compared to water samples from their environment. Data on diet obtained from the fishery catch statistics are analysed to indicate feeding trends.

Results are presented in terms of the geographical distribution of anchovy together with data on length and age composition in summer and winter months. Environmental data are presented in broad, geographical terms and compared with the distribution of anchovy shoals. Anchovy shoals off north and central Namibia are

described in terms of adult, nursery and juvenile functional components of the stock. These components appear to complete various migratory movements through interaction with the complex system of currents. The oceanography of the area is insufficiently understood as yet but could have regulating influences on the stock size. Adults are interpreted as migrating from winter feeding areas to summer feeding and spawning areas. The larvae and early juveniles are considered to be advected by Ekmann drift into more offshore waters where temperatures are warmer and more zooplankton available. These factors are most important for the survival and development of anchovy larvae and early juveniles. Thereafter the juveniles appear to drift or swim southwards, possibly aided by counter-currents. South of Walvis Bay the juveniles form increasingly large shoals as they grow during autumn months. These fish then move steadily northwards and accumulate on the recruitment grounds in the region of Walvis Bay. Here the recruits have increasingly become the basis of the pelagic fishery since the 1970's. There is little direct evidence that juvenile shoals recruit to the Walvis Bay fishery from the peak spawning areas in the far north around Cape Frio. On the basis of environmental data such a movement could theoretically take place, associated with extensive intrusions of Angolan Current water as far south as Walvis Bay.

A persistently recorded stock of anchovies in the vicinity of the Orange River is considered to be separate from the Namibian stock and derived from the Southwestern Cape. Length frequencies

and observed shoal movements indicate a pattern of migration in the Orange River group which supports this hypothesis and which matches the fish migration model proposed by Harden-Jones (1965).

Anchovy shoals occur within the 200m isobath, nearshore, in waters of high phytoplankton density where temperatures range between 15° and 20° C in summer and between 14° and 16° C in winter. These temperature limits form the basis of a suggested geographical system of favourable temperature basins defined by 14°C isotherms in winter and 16°C isotherms in summer (Boyd and Cruickshank 1983). Data on environment and diet coupled with distribution and migration patterns do not support the hypothesis that anchovy are zooplanktophores off Namibia. Rather, they suggest that the anchovy are omnivores, being zoophagous as juveniles but becoming primarily phytophagous as adults. This confirms the observations made by King and Macleod (1976) for anchovy off Namibia.

DEDICATION

A.M.D.G.

1. To my late father whose ambition it was to provide "the highest and best possible education for his two sons", whom he loved dearly

and

2. To all those less fortunately blessed with opportunities for education than that which I have enjoyed.

ACKNOWLEDGEMENTS

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CONTENTS

1. INTRODUCTION

Fed by nutrient rich upwelled waters the Benguela Current System off southern Africa's west coast generates dense populations of phytoplankton and zooplankton. These can support a vast biomass of epipelagic fish. Off South Africa the commercial landings of these fish averaged a total of nearly 500 000 metric tons annually between 1960 and 1980. Off the richer Namibian coast annual totals reached 1.4 million tons in 1968 but have crashed dramatically mainly due to overfishing and in recent years have scarcely reached 200 000 tons per annum despite the switch from pilchard to anchovy. In both South African and Namibian waters the pelagic fishery is based on three major species viz. the pilchard Sardinops ocellatus, the anchovy Engraulis capensis and the maasbanker or horse mackerel Trachurus trachurus. Following the crash in the pilchard fisheries and the introduction of small (12,7mm) mesh nets in the early sixties the anchovy has increased in importance to the fishery and is now the major contributor to the landings off the South African coast. Off Namibia it has played a less dominant roll compared to the other species and only provided the highest catches since 1980. Like the pilchard it too seemed to have collapsed as a resource off Namibia compared to more stable yields off South Africa. In 1987, however, the anchovy has shown a remarkable recovery off both South Africa and Namibia. Landings in the RSA were 595 700 tons and at Walvis Bay 376 346 tons by the close of the season.

This thesis is based on the anchovy Engraulis capensis Gilchrist

which has recently been synonymised with E. japonicus (Houttoyn) but I retain it as E. capensis. The major thrust of the thesis is to identify the functional components of the stock and to interpret the movements of anchovy in Namibian waters.

The pelagic fishery off the Southwestern Cape coast of South Africa has been well documented (Crawford 1980 & 1981; Shelton and Hutchings 1982; Davies et al 1981; Armstrong et al 1985) in terms of spawning, distribution, currents and migration. Off Namibia there is ample documentation on anchovy spawning, fishery statistics and hydrology (Ratte 1973 &1974; O'Toole 1977 & 1980; LeClus 1986; Boyd 1983; Boyd and Cruickshank 1983; Butterworth 1980; Kruger 1983; Kruger and Cruickshank 1982; Kruger and Boyd 1984). Survey methods were developed for direct stock assessment by acoustic, aerial and combined surveys (Hampton 1974; Hampton et al 1979; Cram and Agenbag 1974; Cram and Hampton 1976). Cruickshank 1983a & b, &1984) used qualitative acoustic surveys for mapping pelagic fish distribution to be compared to longshore plankton and hydrological trends and, more importantly, hoped to generate a time series of maps which could elucidate the migration patterns of the fish from early juvenile through recruits to adults. The study has continued with this and presents survey results from 1978/79 to 1985. Although 1984 did not form part of the summer surveys, winter catch data are included and relevant environmental data are summarised from the literature because of the important effects of the El Nino warm event on the anchovy ecology and survival.

2. AIMS

The aims of this project were :

1) to investigate the patterns of distribution and migration of the adult and recruit shoals of the anchovy Engraulis capensis off Namibia;

2) to identify the components of the Namibian anchovy stock

3) to investigate environmental factors and feeding, particularly in relation to their effects upon distribution and migrations of anchovy off Namibia.

d) Diet and feeding habits related to distribution and migration.

This thesis is developed from a limited data base in that

1) The distribution is based on a qualitative assessment of relative densities of fish. Lack of the necessary equipment precluded quantitative assessment of stock sizes for the major components viz. adult and recruit shoals.

2) Curtailment of ship's time meant that I was not able to carry out surveys originally planned to investigate the distribution of post-larval and early juvenile fish, from the major areas of larval density to the proposed nursery and feeding areas. To fulfil this objective, it would have been necessary to sample deeper than 50m, the depth traditionally sampled by ichthyoplankton surveys off Namibia. More appropriate gear such as an RMT-net with an opening/closing mechanism would also have been required. Only a limited number of samples of stomach contents could be compared with the availability of food in the environment. Nonetheless, accepting the limitations of the equipment and techniques described in Section A, and the restraints on ships' time of multi-disciplinery cruises and consequent dependence on other vessels for target identification, there are sufficient data to suggest the interpretations set out. I am confident that the conclusions reached are valid, although the work also shows that there are areas that require further in-depth investigation. Such investigation could alter or confirm the proposed interpretations.

4. RATIONALE

Studies of fish populations using acoustics of the kind used in this study are not unique. Mais (1974 & 1977) conducted regular acoustic surveys of the pelagic fish shoals off California for many years. Johannesen surveyed the Black Sea (Johannesen and Losse 1973 & 1977) coupling the echo sounders to a complex data logging system (echo intergration). Many advances in the development of the methods and equipment have been made since. These are comprehensively summarised and updated in a review on fisheries acoustics edited by Craig (1984). Sophisticated acoustic survey methods are being applied to the anchovy off the South African south-western Cape coast (Hampton et al 1985; Hampton 1987). Cram and Hampton (1976) tried to apply combined aerial fishspotting and acoustic surveys for accurate stock estimates on pilchards but were not entirely successful due to the collapse of the pilchard stock off Namibia.

Mais (1974) has stated that realistic estimates of absolute population sizes of most species surveyed were not possible because of the large magnitude of error from unknown and assumed factors. Anchovy were the only species he studied for which population size could be realistically estimated from acoustic surveys off the Californian coast. Even so his estimates required large confidence limits.

Distribution:

The present study was conducted during a number of summer and winter surveys using echo sounder and sonar in conjunction with various methods of capture for target identification. Quantitative data logging was not applied due to lack of the necessary equipment. Aimed rather at using the relatively simple acoustic equipment as qualitative tools for observation of relative abundance and behaviour, this study looks at the following kinds of information based on the categories of Mais (1974) but in my own order of importance:

1) distribution in space and time;

2) behaviour;

3) relative abundance;

4a) availability;

b) location of areas of commercial concentrations.

Distribution was mapped monthly during summer months from acoustic surveys and from limited survey data for winter months. Relative abundance was plotted on a comparative basis considering shoal frequency and size in relation to area of abundance. From these data it was hoped to identify the stock components, to draw conclusions as to the pattern(s) of migration of adult and juvenile anchovy shoals by relating them to environmental conditions.

Food availability and diet:

King and Macleod (1976) found that the diet of anchovy changed

from primarily zooplanktophagous as larvae to more than 90% phytoplanktophagous as adults. Initial analysis of catch data suggested that this might no longer be correct off Namibia, especially if the diet is analysed for the biomass proportion as well as the numerical frequency.

Kollmer (1963), Visser et al (1973), Kruger (1980 & 1983) and Austin (1980) studied the plankton distribution off Namibia. Visser et al (1973) found that pelagic fish shoals, as observed from aerial and acoustic surveys (Cram and Hampton, 1976), overlapped with phytoplankton distribution such that shoals were found in areas dominated by phytoplankton but with up to 35% zooplankton present also. Kruger (1983) found that off Namibia phytoplankton is mainly confined within 25 miles of the coast particularly, to the north of Cape Cross, with peak distribution between 5 and 15 n. miles offshore. Cruickshank (1983a) found that anchovy shoal distribution corresponded to high concentrations of phytoplankton. The present study examines the diet of anchovy compared to the availability of plankton in the immediate environment. Contrary to expectations it confirms the findings of King and Macleod (1976) as well as Visser et al (1973) for Namibian waters and shows some selectivity towards certain diatom genera consumed relative to their abundance in the water column. The results are closely similar for different regions of the Namibian coastal waters as well as in different months of the year.

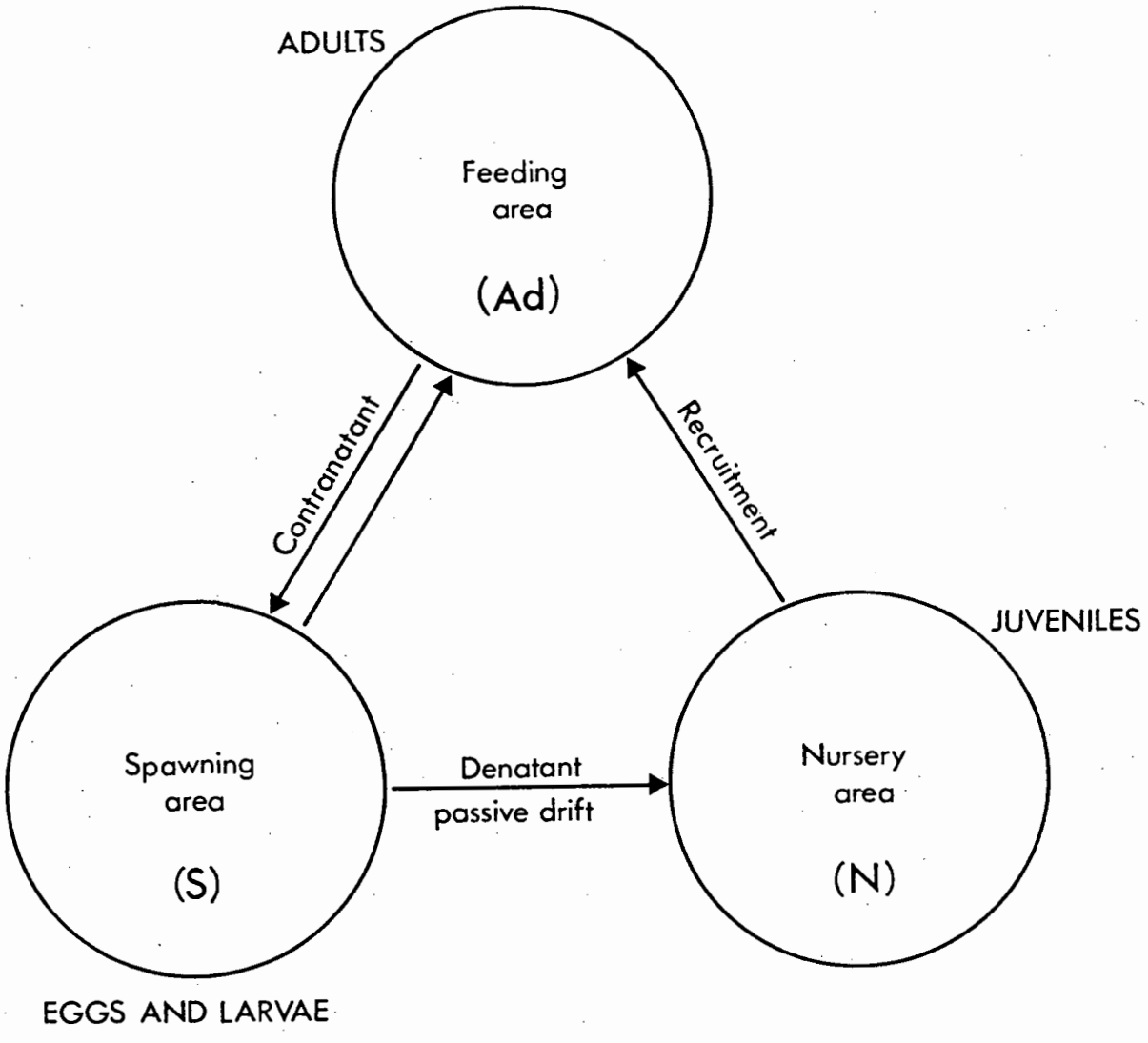
Hydrological environment:

Hart and Currie (1960), Stander and De Decker (1969), Visser et al (1973), O'Toole (1977 & 1980), Boyd (1979 & 1983) and Shannon (1985) Shannon et al (1986) have fully described the oceanographic regimes of the whole Namibian region. Hydrological sampling carried out in conjunction with this study (Boyd 1983, and Boyd and Kruger 1984) confirm their findings particularly as described by O'Toole (1980) for the upper 50 m.

Off Namibia the upper 20 m are found to be the depths most frequented by anchovy shoals of all ages. Kruger and Cruickshank (1982), Boyd (1983), Cruickshank (1983b) and Cruickshank and Boyd (1985) have compared the vertical and horizontal distribution of shoals to environmental conditions. They found the shoals strongly influenced by temperature distribution. This study confirms this conclusion and examines the influences of dissolved oxygen, chlorophyl maxima and plankton on anchovy distribution.

Migration model:

Harden-Jones (1965 & 1968) has advanced a model for migration within populations of fishes (Figure 1). This model proposes three seperate areas within a population's range, occupied by different components of that stock. There are areas suitable for winter-feeding adult groups(Ad). They migrate, usually contranatant, to the summer feeding/spawning areas (S). Atritic adults return with the current to their original feeding area (Ad),



from Harden - Jones (1965)

Figure 1 FISH MIGRATION MODEL (after Harden-Jones 1965)
Ad= Winter-feeding adults S= Summer spawning/feeding area
N= Post-larval feeding area

eliminating competition with their offspring. The newly spawned group move passively, with the current to a nursery area (N), generally one of most favourable food abundance. The obvious benefit of this strategy favours survival of the new generation. They in turn mature and migrate (recruitment), generally against the current, to the adult feeding grounds.

Anchovy migration patterns off the South and Western Cape, as presented in the literature (Shelton 1979; Crawford 1980 & 1981; Shelton and Hutchings 1982; Badenhorst and Boyd 1981), apparently conform (Figure 21) to the expected Harden-Jones model. In this thesis the Namibian and Orange River anchovy stocks are examined and discussed, exploring the agreement with, and important differences to the Harden-Jones models (1968).

It is my hypothesis that the Namibian anchovy stocks do not show a simple fit to the original Harden-Jones model (1965) but that the model can be fitted to the anchovy shoals in the Orange River area and used to explain the role of this group as a part of the Southwestern Cape stock.

SECTION A : METHODS

1. ACOUSTICS

(a) Equipment

Central to the whole project was the acoustics work using a 120 kHz scientific echo-sounder beamed vertically downward from the hull of the research ship Benguela and a 24 kHz sonar beamed horizontally (-3°) at 90° to port (left) of the ship's track. The echo sounder was set to scan only the upper 250 m of the water column and the sonar range was kept at 250 m.

Specifications and settings used:

	ECHO SOUNDER	SONAR
type	SIMRAD EK-S (scientific)	SIMRAD SB-2
frequency	120 kHz	24 kHz
TVG	20 log R + αR	-
recorder gain	5 - 6 (out of 10)	4 - 6 (out of 10)
power	1/10 = 40 W	1/10 = 400 W
beam width	20° (between -3dB points)	vertical 12° horizontal 16°
pulse length	1.0 ms	3 ms
range	250 m (125m in shallows)	250 m
beam angle	- 90° (vertically downward)	- 3° (range - 3° to 7°)
effective depth	250 m	44m

On the purse-seine vessels the following types of fishing sounders were used:

Persequor	50 kHz Furuno	30 kHz Simrad SK-3
Gregory Justin	50 kHz Furuno	30 kHz Simrad SK-3
Boetie Akie	50 kHz Furuno	30 kHz Simrad SK-3
Christiaan DeWet	50 kHz Furuno	30 kHz Simrad SK

It must be stressed that the above values are all nominal. They were not directly measured or calibrated during surveys. Due care was taken to obtain reliable recordings of fish shoal distribution by establishing and adhering to optimal equipment settings. The ranges and settings were chosen so as to give the most accurate shoal dimensions (Figures 3 & 4). Specifications and range settings are critical for quantitative work but for the type of survey undertaken in this study it is most important to maintain constancy within fixed range limits and therefore to obtain comparable data between surveys and from year to year. The results presented are primarily qualitative and not quantitative because an echo integrator system was not available during the period of survey. Such equipment would have been essential for accurate determination of fish density for stock estimation purposes but relative indices of distribution and density were sufficient for the purpose of this study.

To minimise the effects of surface reverberation and refraction through surface layers of different density, the sonar beam was aimed 3^{o} downwards from true horizontal. This was increased to

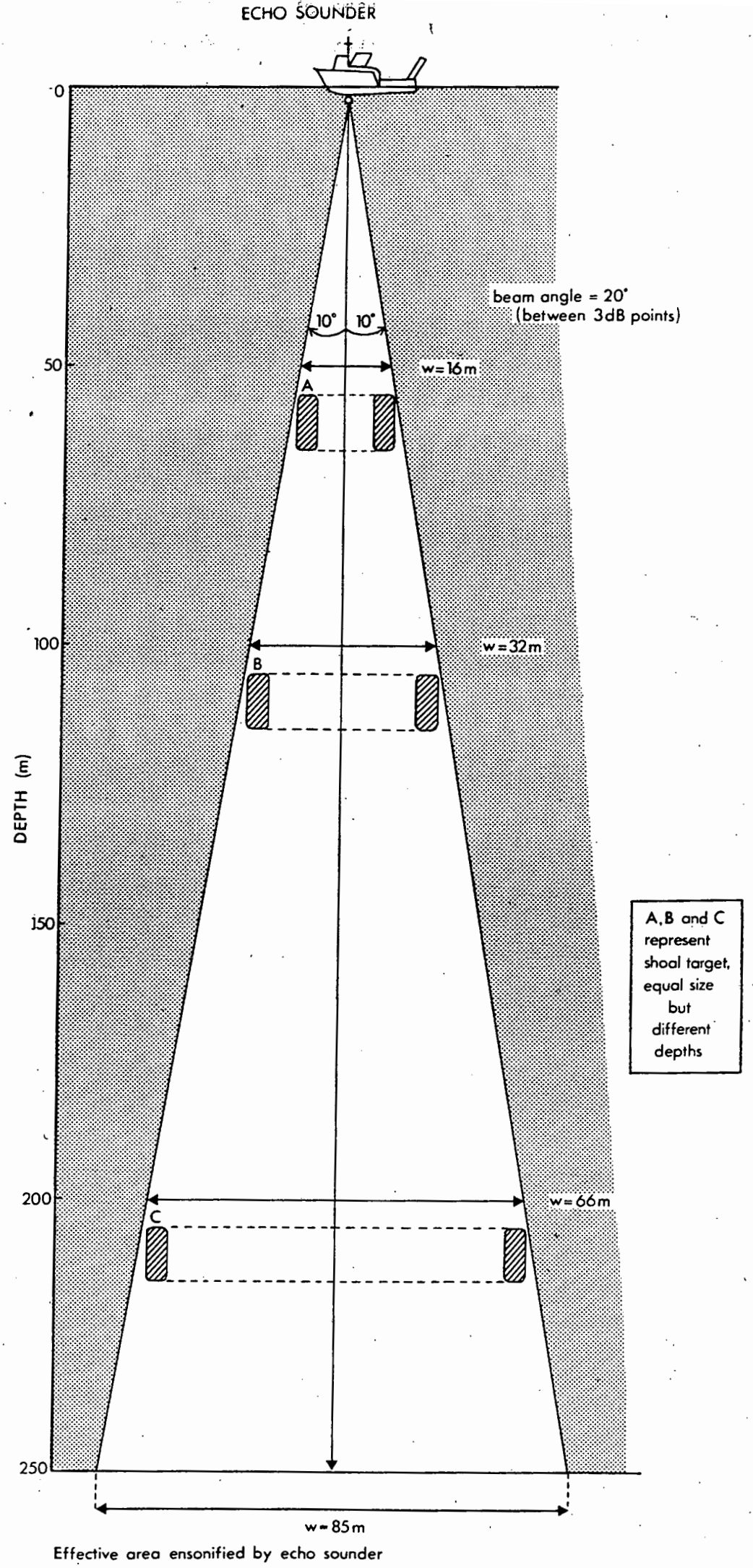


Figure 2 ECHO SOUNDER BEAM DIMENSIONS - RANGE DISTORTION INDICATED

between -5° and -7° in rough weather (20-30 knots wind strength) because under these conditions surface reverberation increases due to increased aeration of the surface water and greater rolling of the ship. Because these problems are greater over longer ranges, the range was limited to the shortest available (250m). It was found that shoals were detected over the full 250m range at times, although the majority were detected within 100m of the ship's track. From simple geometric calculations (Figure 4), the sonar records were considered to reliably reflect shoal distribution in the upper 20m over this range, while it was estimated that under good conditions shoals as deep as about 44m would havebeen detectable at 250m range.

The vertical beam of the echo sounder was not so sensitive to bending but Figure 3 shows how similar sized shoals would have seemed to be larger if they were deeper in the water because they would have been ensonified for longer periods in the wider portion of the beam. The echo sounder was kept at 250m range except when it was adjusted to 125m in shallow waters. Most pelagic fish shoals occur in the upper 100 m off Namibia (Agenbag 1974; Cruickshank 1983a), in this study, anchovy shoals were always found within the 200m isobath, mostly confined to the upper 20 meters from the surface by day or night. This was well within the 100m range within which the echo-sounder's TVG compensates for range-dependant loss of signal strength. In contrast, the sonar TVG does not compensate accurately for range-dependent loss in

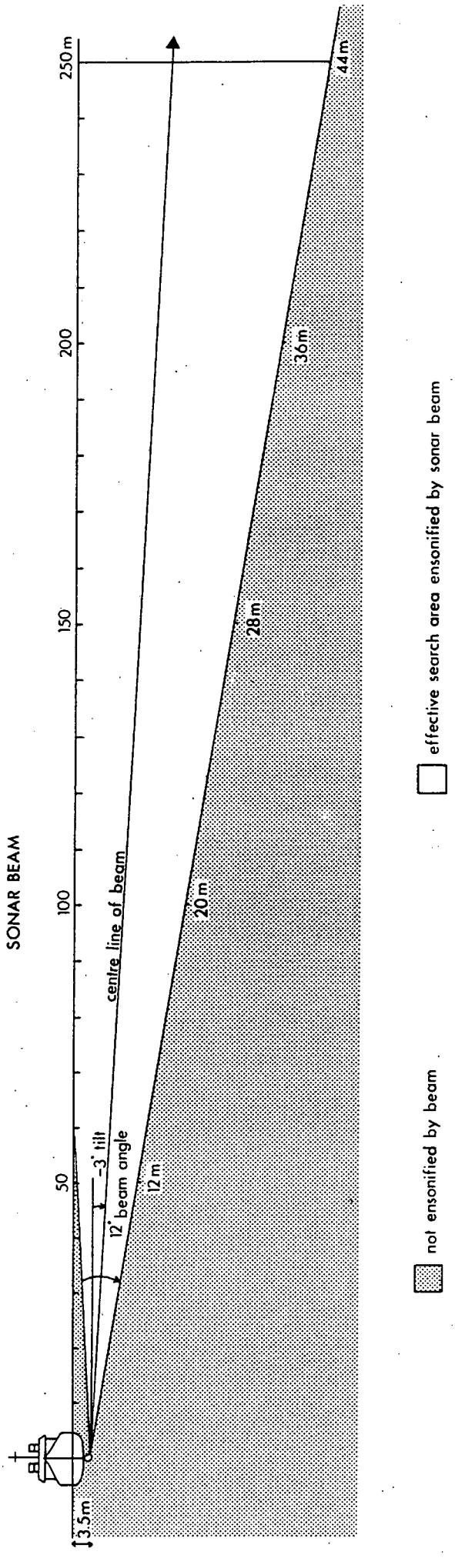


Figure 3 SONAR BEAM DIMENSIONS

the sonar signal which is far more complex than in vertical echo-sounding. Nonetheless, as there is partial range compensation in the sonar receiver, in this study no corrections for range dependent loss of signal were applied to the sonar records. Since there was no means of guaging shoal signal strength other than by the intensity of the image on the paper recording, which is an extremely crude method (Hampton *et al.* 1979), for the purposes of this study, all shoals were treated as if they had equal density. General details of the factors influencing accuracy of both echo-sounder and sonar survey results are given in Forbes and Nakken (1972), Mitson (1983) and Craig (1984).

2. SURVEY PRECAUTIONS

Details of the factors influencing accuracy of acoustic survey results are given in Forbes and Nakken (1972) and Mitson (1983). However, the following is a general outline of some pitfalls which can arise in the collection of data using sonar and echo sounder records for estimates of relative density as in this study.

It can be seen from Figure 4 that the beam angle will affect the volume of surface water near the ship which will not be ensonified. The region of this "blindness" will vary according to the pulse length of the sonar beam. Shoals too close to the ships track may escape detection by being obscured in the ship's wake.

Ship's speed and recorder paper speed could influence interpretation of the records. Slow speeds enlarge and faster speeds diminish the apparent size of shoals on the recorder and also affect the apparent spacing of shoals. This was important when comparing acoustic records from the research ship and the catcher vessel; e.g. the research ship was capable of 12 knots maximum speed but generally steamed at ± 11 knots (average 10.5 knots) whereas the purse-seine vessels contracted for target identification were capable of a little over 10 knots but averaged close to 9.5 knots sustained speed. Thus at the same paper speeds the dimensions of shoals could have appeared 10% larger on the echo records of the fishing vessels.

The detectability and estimation of density can be markedly affected by fish behaviour and by highly clustered or patchy distribution. Anchovy are usually concentrated by day into shoals that are larger and denser than at night and tightly clustered, usually close inshore. At night these shoals spread out over wide areas (pers.obs.) and are so close to the surface (ie. in the upper 5m) that they are difficult to detect acoustically but they may be visible from the ship due to disturbance of bioluminescence Highly clustered shoals, invisible by day, are more likely to go undetected than widespread small shoals or open surface fish covering a wide area. This leads to greater sampling variance by day. Ship avoidance could seriously affect detectability but in a previous study Hampton (1974) found during combined aerial and

acoustic surveys that fish detection by the hull-mounted transducer was not seriously affected by avoidance behaviour. The sideways beamed sonar and visual records at night were considered to be sufficient safeguard against avoidance behavior of shoals. In February and March 1982 it was possible to compare replicate transects of a large shoal group near Möwe Bay with roughly simultaneous cover from a spotter-aeroplane flying at 500 ft above sea level (Agenbag *et al*. 1984). The results of the acoustic surveys, repeated for night and day, and the aerial survey done only at night were almost identical.

Anchovy are generally found in homogenous shoals off Namibia with only small percentages of other species (usually juvenile pilchard of similar size) present. Hampton (1974) and Hampton *et al* (1979) found the same was true for pilchard. At night when spread out at the surface, anchovy shoals were sometimes observed to overlap with horse mackerel shoals (Cruickshank 1983a). However, the behaviour of the three species and the resultant differences in effect on bioluminescence could be readily distinguished by shipboard observers. Hampton *et al.* (1979) also noted that fish shoals could be located by observation of bioluminesence in the water at all times of the year. It was thus possible to estimate the rough proportions of either of these species and take this into account in the relative density estimates. It was thus possible to include an estimate of the rough proportions of the species in the determination of relative density.

Besides signals from underwater targets the receiver of a sonar system is subjected to noise which can mask the echo signals from shoals, *e.g.* noise caused by the ship's own machinery and movements or by cavitation bubbles formed by the propellor. To reduce reflection of this noise from the bottom it was necessary in shallow water to keep the vessel to a maximum of 10 knots. Jelly-fish and surface reverberation caused inconsistent but sometimes prominent interference. These could sometimes appear to be like shoals of fish or like loose layers of fish typical of anchovy at night. Where target catches were not available it was necessary to rely on experience and the information from small-net hauls and shipboard observations during ichthyoplankton sampling.

3. TARGET IDENTIFICATION

A major problem in acoustic surveys is identification of the targets recorded. Direct sampling was carried out by employing various means of fishing such as purse-seining, midwater trawling and smaller, rectangular midwater trawls (RMT's). There were also indirect methods which helped to give a reasonable guide to target identity, such as the coincidence of pelagic shoals with that of high egg concentrations sampled on the same evening or by obtaining samples from fishing vessels operating in the close vicinity and likely to be working on the same shoal group (Forbes and Nakken 1972; Mais 1974; Cruickshank 1983a). Experience of shoal configuration and behaviour can be used (Hampton 1974;

Mais 1977; Cruickshank et al 1980; Cruickshank 1983a) as is done by airborne fish-spotters in identifying shoals (Cram and Hampton 1976). Similarly visual identification of fish at the surface, particularly at night during high bioluminescence (Hampton et al 1979) can help to identify shoal targets due to species-specific behaviour. For example when anchovy shoals scatter from a ship they form characteristic, parallel rows away from the disturbance (pers.obs.), giving the appearance of "steps" (Afrikaans = trappe) in fisherman's terminology. Most of these methods were employed at some stage during the surveys for additional information on targets.

The research ship Benguela was not equipped for midwater trawling during the major period of these surveys, so the SFRI hired a commercial purse-seine vessel to work in tandem with the research ship. A purse seiner was used from the 1978/79 summer until the 1981/82 summer survey to identify the fish shoals detected as described under "Survey Methods".

Commercial fishing vessels were not available in winter because of their involvement in the fishing season. Thus for the studies of shoals in relation to environmental conditions, shoal groups were chosen dependant on whether they were being fished by the commercial fleet. Samples could then be collected from one or more fishing boats as the fish were being pumped from the nets. In addition target identification was achieved by other means of

direct sampling from the research vessel.

Midwater trawling with a commercial Engels 308 net was tried but was only successful during the June cruises in the winters of 1984 and 1985. Prior to this the operation of the net from the R.S. Benguela was beset with mechanical problems and malfunctions and never performed properly off Namibia. In confirmation of this purse-seiners alongside caught plenty of recruit anchovy but the trawl captured less than 2 kg on the same targets.

Rectangular midwater trawls, viz. RMT-8 and RMT-2 nets, described by Robertson (1979) and Robertson et al (1981) were introduced with slight adjustments. The RMT-8 net opening was 8 m^2 and was fitted with anchovy (12.5mm) mesh netting. The RMT-2 had a roughly 2 m^2 opening and was fitted with Frymo (4.5mm) mesh netting (Robertson et al 1981). After experimentation at 2-4 knots it was found that both nets performed best, in terms of stability, mouth opening and target depth when hauled at 3 knots. Towing speeds outside the 2-3 knots range was often responsible for erratic performance in the water such as twisting of the net and inability to maintain target depth. Also, with the inevitable abundance of jellyfish off Namibia, there was greater risk of bursting the net at higher speeds. The RMT nets were used with a "U^3" opening and closing mechanism described by Robertson et al (1981). Using a Simrad "Trawl-link" net-sonde rather than the one described by Robertson (1979), it was possible to lower

the net to target depth before opening and to close the net when satisfied that it had passed through a particular target. This was then an accurate means of identifying targets, as shown by the result of the April 1983 survey. Unfortunately these nets became available too late in the survey programme to be put to more effective use in the survey as a whole.

A neuston net was used at night during some of the winter cruises. This did successfully capture anchovy larvae and juveniles and even some 10 cm adults at the very surface sometimes even when other, deeper-reaching nets failed. However, a neuston net is primarily intended for zooplankton. It is a qualitative not a quantitative sampler. Catches with the net were primarily useful in indicating identity and behavioural trends, *ie*. whether anchovy were present in the upper meter of the water column at night, where they were not detectable by echo sounder but visible to the naked eye when there was strong bioluminescence.

4. DISTRIBUTION

Combining the data from the acoustic records of both survey and catcher vessels plus target identifications, the geographic distributions of the major epipelagic and mesopelagic fish species were mapped out. To do this the distribution of anchovy was ranked according to a scale of relative densities indicating the following:

1. presence of some targets; scattered shoals or occasional patches (10-25 /km^2) of small shoals;
2. fairly dense aggregations (25-100 /km^2) of small and medium shoals of commercially viable size;
3. large shoal groups consisting of dense groups (75-210 /km^2) of medium and large shoals and sometimes massive "blocks" (up to 2kms long) of fish from the surface to the bottom (usually close inshore).

Scale 1 was considered "not commercially viable" because such shoals were unlikely to yield more than 10 metric tons per throw of a purse-seine net. Scale 2 was considered moderate but commercially viable because the shoal sizes could be expected to yield, on average, tonnages of 20 - 50 metric tons per throw. Scale 3 was the optimum shoal density (about 100-200 /km^2) for commercial purposes and could be expected to yield catches in excess of 100 metric tons per throw. Figures 5 to 7 illustrate examples of the three grades of density that are mapped out in Section B.3.

A relative index for the above rankings mapped in each month of survey was applied per degree of latitude and totalled for all the surveys. Also, the frequency of shoal detection compared to the total number of surveys was listed per degree of latitude. Both sets of values (Table 1) were subjected to a Chi-squared test for randomness and were found to be highly signficant at the 1% level.

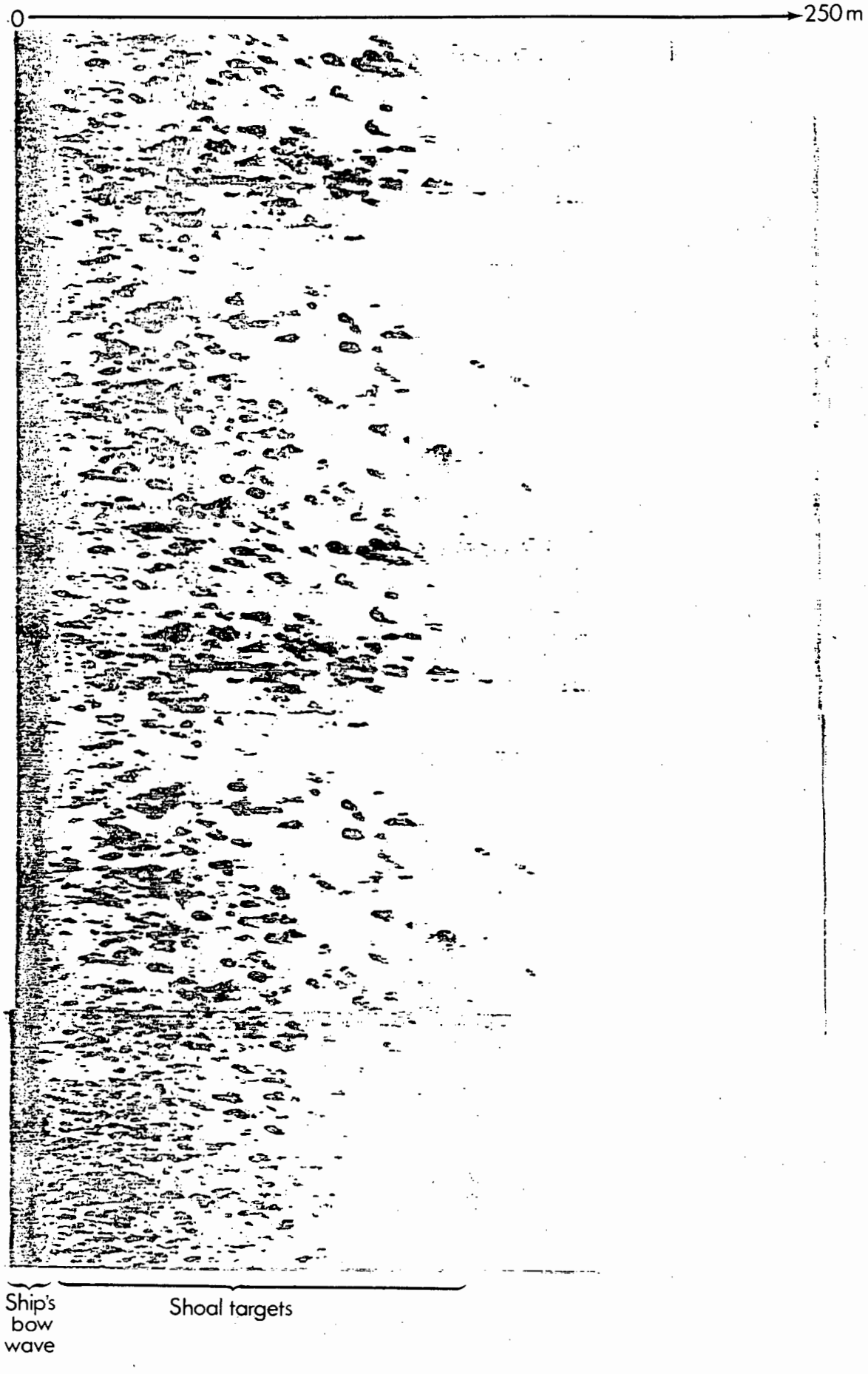


Figure 4 SHOAL DENSITY: GRADE 1 - NUMEROUS SMALL SHOALS

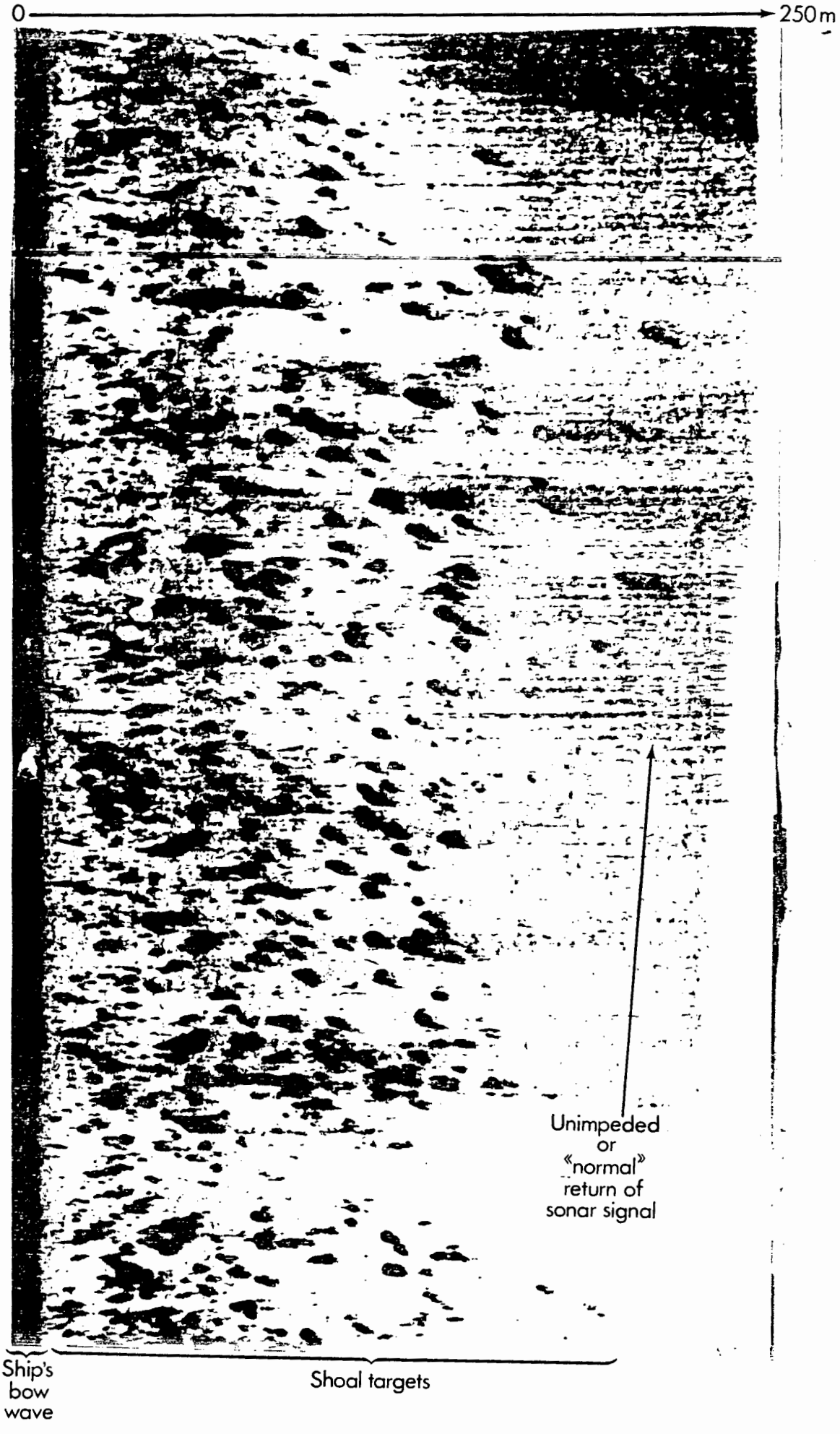


Figure 5 SHOAL DENSITY: GRADE 2 - MANY MEDIUM-SIZED SHOALS

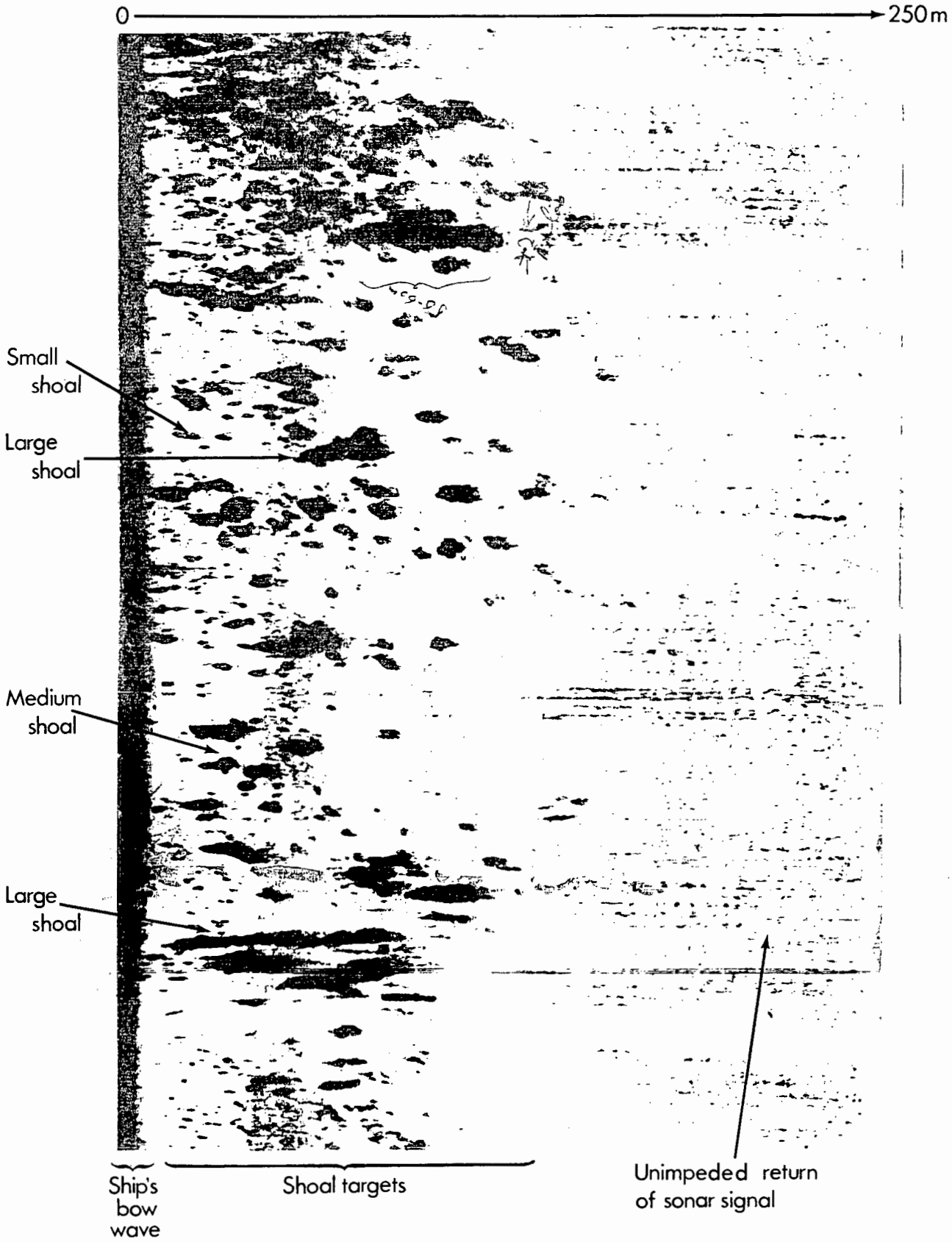


Figure 6 SHOAL DENSITY: GRADE 3 - LARGE SHOALS

5. SURVEY METHODS

Maps of the basic survey grid and an extension of this grid carried out in the southern Namibian region are presented in Figures 8 & 9. Initially the distance between the lines was 20 nautical miles but this was later changed to 30 miles due to fuel and budget economies. The 24 survey cruises covered the area from just south of the Cunene River (17° 30'S) to Lüderitz (26° 40'S). Twenty of these were carried out in combination with intensive hydrological and ichthyoplankton surveys (SWAPELS).

Starting in November 1979 and continued until December 1980 an acoustic monitoring survey of the grid was conducted from r.s. Benguela during the SWAPELS surveys. In conjunction with this a commercial purse-seine vessel was contracted to follow the research vessel. It was used to make catches from targets selected by the author from the Benguela's acoustic records. The catches were sampled for species composition. In this way as many acoustic targets as possible were identified. An overall picture of the geographic distribution of pelagic shoals with species identification and length frequency could then be plotted.

There were problems in that the scientist in charge (SIC) had to convey by radio his initial target selection from the research vessel to the scientist aboard the catcher vessel who in turn, had to interpret the catcher vessel's acoustic records according

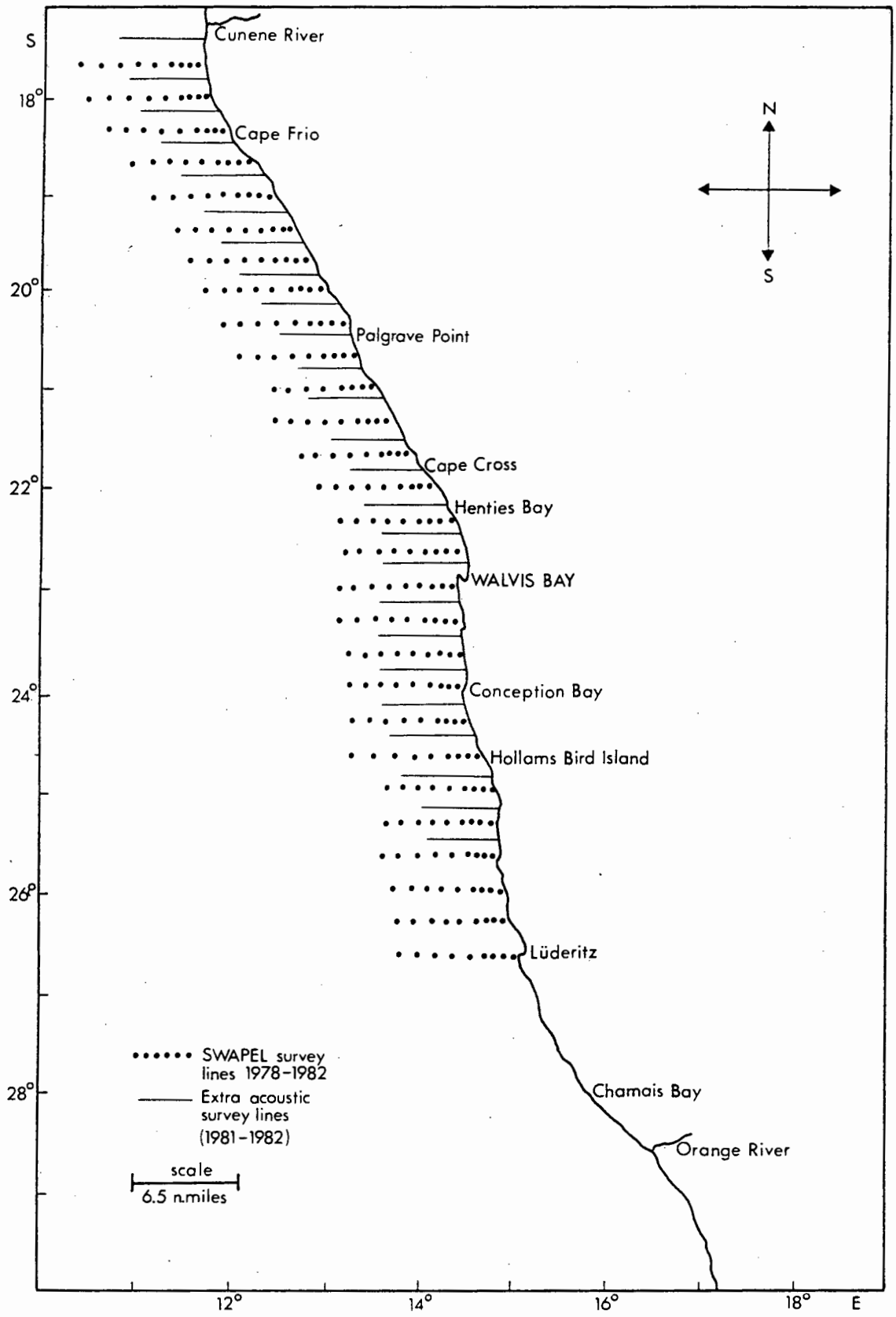


Figure 7 SURVEY GRID OFF NAMIBIA, 1978 -1985

to the position and description given by the SIC. This made him dependent on the experience and assistance of the fishing skipper. The interpretation of the fishing skipper, however helpful, is biased by what a fisherman considers a worthwhile target or one on which he is prepared to throw his net. Thus successful sampling became dependent on large targets yielding a "good" catch. This was wasteful in terms of unnecessary mortality of large quantities of the fish caught and it involved scientists in an apparent condonence of dumping. It did not fulfil the scientific requirement to identify echo targets of all shapes and sizes at all hours of day and night.

Another problem was the time lapse between detection on the research vessel and arrival of the catcher vessel. Ideally the latter steamed just behind the research vessel and could fix onto a target soon after detection by the research ship. In practice each cast of the net takes about two or three hours. Inevitably, this led to delays in reaching selected targets of two to several hours. Compromises had to be made sacrificing some targets simply to keep the catcher vessel in touch with the survey vessel and current targets. In the elapsed time between initial detection and attempted sampling, the shoals could have moved many miles in any direction or might not have been available or even detectable due to a different behaviour according to time of day. It was difficult to reconcile target records of the two vessels and there could have been doubt about whether samples

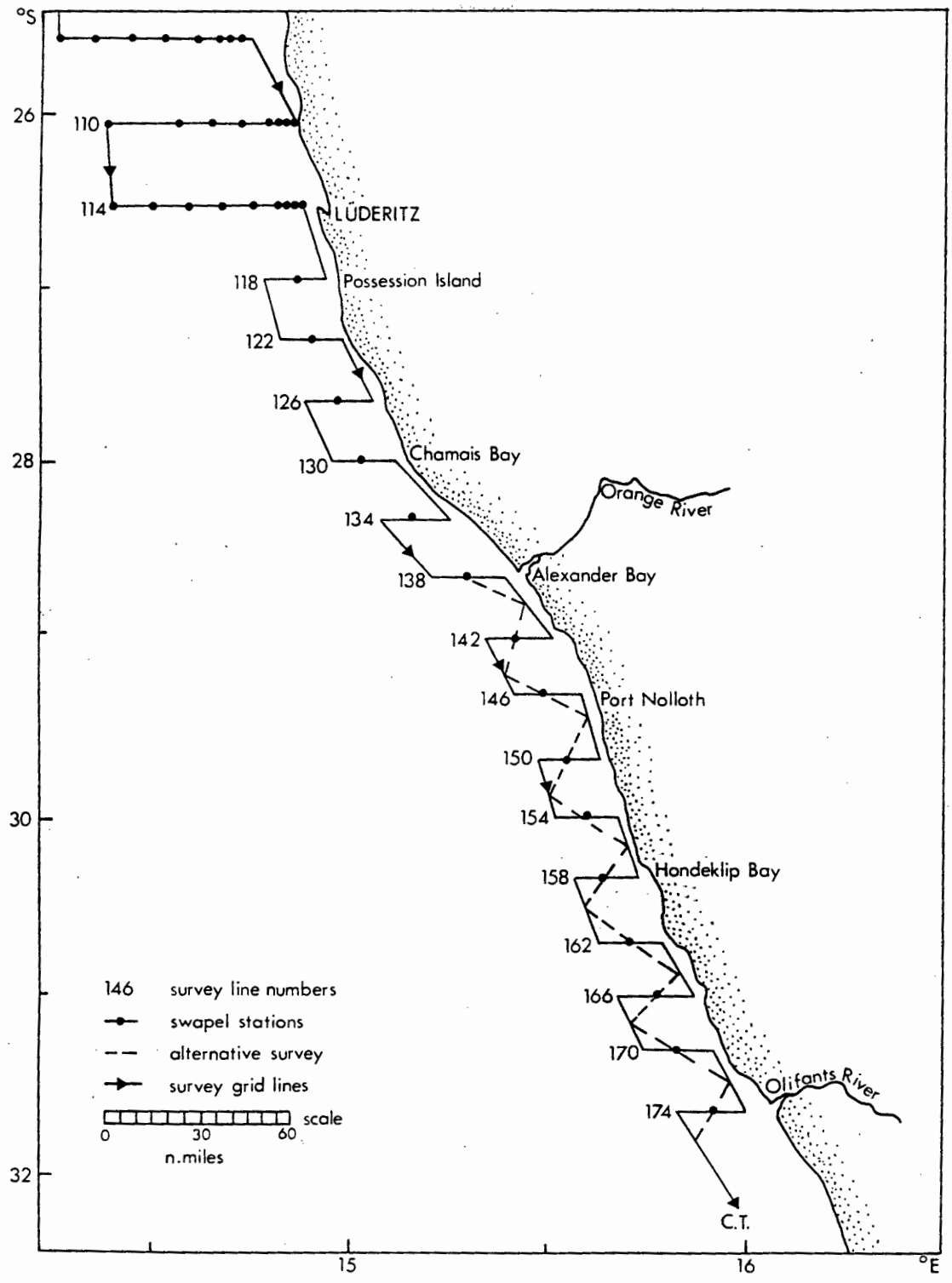


Figure 8 SURVEY GRID EXTENSION SOUTH OF LÜDERITZ

Zig-zag grid was often followed on northbound passage or if survey time limited and the squared grid southbound.

were truly representative. Because of these problems the strategy was modified from January 1981 to use the catcher vessel for sampling targets more effectively. However, the catcher vessel operating as a satelite to the survey ship made catches alongside the Benguela but inevitably was delayed from 2 to 7 hours while making catches. This approach was modified in January 1981 as experience showed that the catcher vessel could be utilised to sample required targets more effectively and the catcher vessel could function as a duplicate research vessel. The research ship continued its usual SWAPELS grid survey (Figure 8) up to 65 miles offshore with the acoustic equipment still operated for 24 hours a day. The author(SIC) travelled on the purse-seine catcher vessel which basically followed the research vessel as before but only travelled out to 45 miles from the coast unless dense shoals were still being detected at this distance. In such cases the course was continued until the shoal group was no longer detected. The catcher vessel followed a more intensive grid with survey lines only 10 miles apart. The timing was such that the two vessels were working in the same latitudes simultaneously, overlapping frequently. Descisions on which targets to identify were taken by the author aboard the catcher vessel. The advantage of direct communication between the author and the skipper studying the same acoustic record meant that the scientist could ensure identification of the targets selected by him to fulfil the objectives of scientific investigation of fish abundance and behaviour. He could also be sure of exactly which targets were

identified by the catcher vessel's net. Relating this to what was recorded by the research vessel Benguela was a much easier task than in the former strategy. Replicate samplings were made in the day and night when required. Also, temporary diversion was possible to measure the extent of a shoal group if time and the weather were favourable.

Measurement of a shoal group was carried out as in Figure 10 taking accurate bearings at each turning point. A number of shoals would have been passed over by the time a decision to sample and a cast had been made. The vessel was thus within the boundaries of the shoal group (Figure 10). After completion of the catch the boundaries of the group were located by steaming until no more shoals were detected then re-entering the shoal group by a short reciprocal course then turning at right-angles on re-entry etc., until the dimensions of the group had been delimited (Figure 10a). The direction of rotation was irrelevant (i.e. clockwise or anti-clockwise) and the exact strategy was flexible according to the group formation encountered. Later the preferred strategy was as in the second diagram (Figure 10b). A shoal group was first crossed completely then by means of a diagonal course the "top" end of the group was located. The vessel then steamed along the whole axis of the shoal group. Accurate bearings were noted at the "top" and "bottom" edges of the group and the intervening distance measured. By a progression of courses diagonal and perpendicular to the axis the vessel made its way

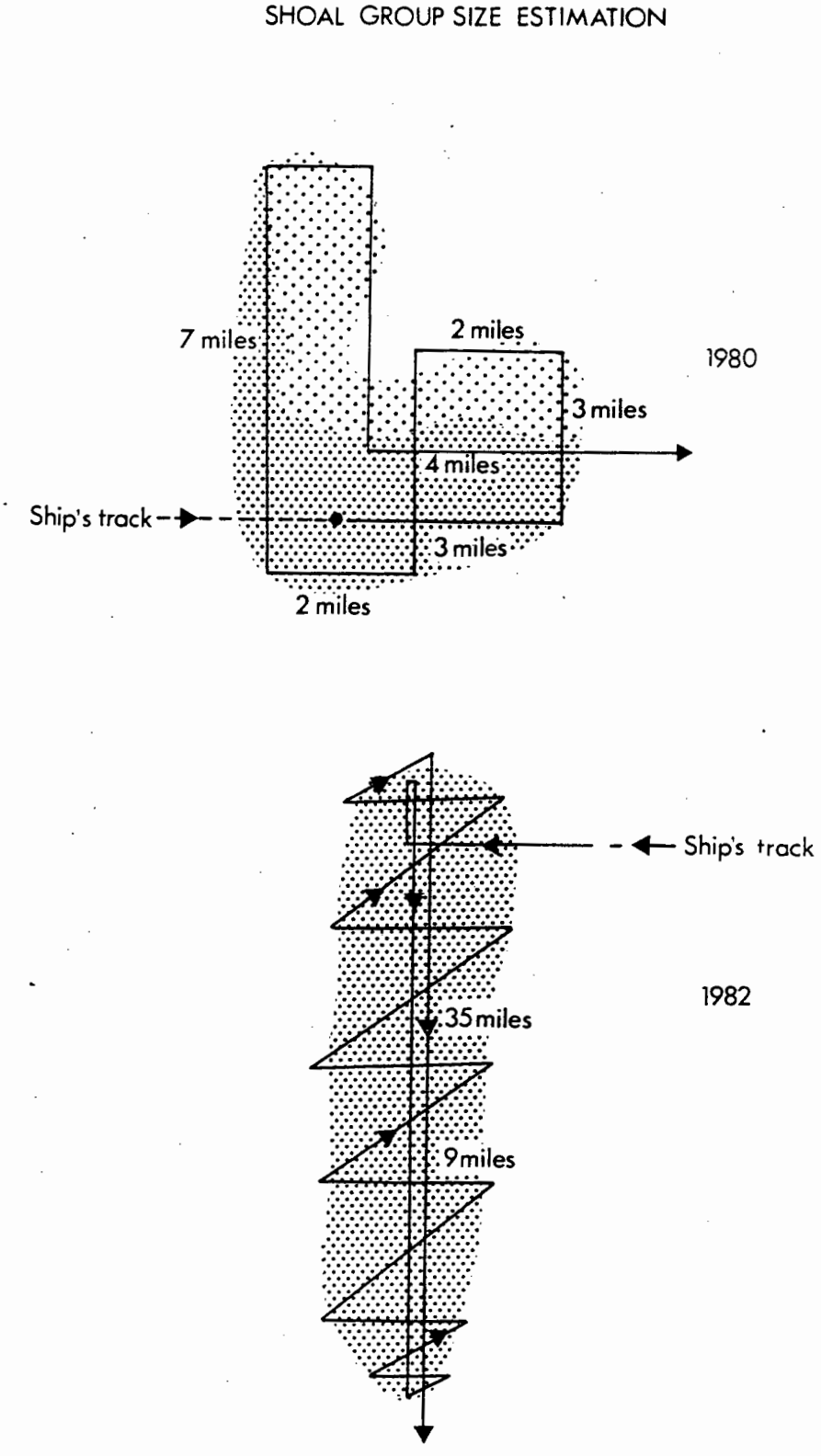


Figure 9 EXAMPLES OF SHIPS COURSE TO INVESTIGATE SHOAL GROUP SIZE

back to the "top" measuring the (variable) width of the shoal group. The measurement of shoal groups in this manner was greatly facilitated by the occasional presence of an aerial spotter-plane or by replicate surveys of the area at different times of day or on subsequent days.

The summer and autumn distributions were monitored during approximately monthly surveys from October 1978 to April 1982. As catcher vessel availability became more limited each summer, use thereof had to be maximised. Thus, effort later concentrated on late summer and autumn when anchovy fish densities were found to be optimal for survey. The surveys were again conducted from January to March/April in 1984 and 1985 but no catcher vessel was available. Target identification relied on experience in interpretation of the typical shoal patterns allied to ancillary data such as egg and larval distributions. In all, 24 summertime cruises and 6 wintertime cruises were completed. Selection against spring and early summer months because of limited ship's time, though not desirable, was considered acceptable for this study because only horse mackerel were detected in large concentrations in early summer months.

Shoal Ecology:

In winter, studies on shoal ecology were aimed more at understanding environmental influences on shoal behaviour than on total distribution and abundance. Only part of the SWAPELS grid

was steamed: up to 40 miles offshore with survey lines 30 miles apart and extending between Hollams Bird Island and Rocky Point (usually only to Palgrave Point because of restrictions against fishing further north). Routine hydrological sampling lines per degree of latitude were completed between 21°S and 24°S. Depending on shoal distribution and abundance, a large shoal group, if actively fished on by the commercial fleet, was selected so that fish samples could be collected while sampling the hydrology and available plankton.

6. HYDROLOGICAL SAMPLING

Surface temperatures and salinities were recorded continuously by means of an Ocean Instruments thermosalinograph installed on board the research vessel. Temperatures, salinities, dissolved oxygen, and nitrate were recorded at 0, 10, 20, 30, 50, and 100m depths plus surface chlorophylls, all at 5, 10, 15, 25, and 35n.miles offshore for each degree of latitude from 21°S to 24°S. At all stations associated with the shoal groups during winter cruises, dissolved oxygen, nitrate, salinity, temperature and chlorophyll were sampled at the above depths, routinely every four hours for at least 24 hours.

Two kinds of water sampler were used, a Nansen-Pettersen bottle and NIO-bottles. The Nansen-Pettersen bottle is more reliable for temperature readings but collects a small sample and

takes much more time because it must be lowered to each sample depth, brought to the surface, subsampled then lowered to the next depth. During rough sea conditions there can be significant variation in wire angle and hence resultant depth sampled between the first and last samplings. The NIO-bottles were therefore favoured to provide an instantaneous sample profile of the whole water-column and thus also to save time.

Salinity samples were collected and kept for analysis ashore where conductivity was measured using a Beckman Induction Salinometer (accuracy 0.003%) calibrated each time with standard seawater ("Copenhagen water"). Conductivity was converted to salinity using UNESCO International Oceanographic Tables. Dissolved oxygen was measured on board using the modified Winkler Method described by Strickland and Parsons(1972). Nitrate and phosphate were analysed using an autoanalyser based on the processes described by Strickland and Parsons(1972).

7. PLANKTON SAMPLING

An N50V plankton net (50cm diameter) was towed vertically through the upper 50-m at each station on the grid and at ecology stations. Settled volumes of phytoplankton and zooplankton were determined as described by Nel (1968) and Kruger (1983). This provides a clear guide to the presence or absence of phytoplankton and zooplankton and their ratios. Their relative abundance was

then geographically mapped out (Le Clus & Kruger 1982; Kruger 1983; and Kruger & Boyd 1984).

Chlorophylls, which are regularly used as a guide to phytoplankton abundance (Hutchings,pers.comm.; Brown 1984), were measured at 0, 5, 10, 20, 30, 50,and 100m depths at all ecology stations. For this a two-litre sample of water for each depth was separately filtered onto GF/F filter papers under pressure, using a suction pump apparatus, then frozen in darkness until analysed ashore according to the spectrophotometric methods in Strickland and Parsons (1972).

The diatom composition in the vicinity of shoals was examined by taking water samples (150 ml) from the NIO-bottles. These were preserved with 1 ml of formalin and taken ashore for analysis. These samples were then diluted and analysed according to the standard methods described by Nel (1968). Counts of more than $50x10^3$ /l were recorded as "dominant", $20\text{-}50x10^3$ /l as "abundant", $0.4\text{-}20x10^3$/l as "common", and less than $0.4X10^3$ /l as "scarce".

Differences in the variance of samples obtained from different sampling areas and at different depths at the same station were statistically compared by means of F-tests and t-tests. Because no significant differences were found between the sample means of the depth intervals ($F^{0.05}= 2.98$, $t^{0.025}= 0.30$) it was considered valid to intergrate the samples of the water column from 0-50 m

depths. The validity of this assumption was confirmed by Hutchings (Sea Fisheries, pers.comm.).Thus, samples collected at 0, 10, 20, 30, 50, and 100m depths were grouped into Group I (0-10m), Group II (20-30m) and Group III (50-100m). The variance between different sampling sites along the coast were not found to be statistically significant ($F^{0.05}= 2.82$, $t^{0.025}= 0.013$). It was thus, considered valid to compare the results.

8. STOMACH CONTENTS ANALYSES

(a) Sampling from survey catches:

Fish samples were collected at midday as the fish were being pumped from the net of whatever vessel was closest to the research vessel's position in the shoal group. For each such daily sample the contents of 20 fish stomachs were identified in detail. These were compared with samples taken from commercial boats as the fish were landed at Walvis Bay. No differences in fish size composition or gut contents were observed between the midday samples and the landings from commercial catches made throughout the day from the same shoal group. The subsample of 20 fish thus provided a uniform set of data obtained over a period without bias for different feeding rates at different times of day. The study by King and Macleod (1976) concentrated on night time samples whereas, during this study, fishing activity occurred almost exclusively in daylight hours. It was believed that daytime feeding patterns might show a different ratio of food organisms

to reflect the differences in shoaling behaviour and possibly feeding stratergies as described by Angelescu (1982). A simple 50:50 selection of males and females during this subsampling in March 1982 showed no difference in diet accoding to gender. After sampling the fish, the research ship then stayed with the shoal group and monitored the hydrological developments every four hours and any changes in the shoal behaviour. Such monitoring was continued for at least 24 hours.

Anchovy stomachs and their contents were weighed (wet) whole on a balance. Displaced volumes of these whole stomachs were also measured. Stomachs were then dissected and their contents washed out into solution. Emptied stomachs were then all re-weighed together and their total displaced volume determined. The mean empty stomach weight and volume were calculated and subtracted from the individual weights and volumes of full stomachs.

The solutions containing the stomach contents were each diluted to 10ml for measurement of volume using a modified Yashnov-meter according to the methods described by Robertson(1972) and Kruger (pers.comm.). A Yashnov-meter was standardised then dried thoroughly. In turn, each stomach content sample was added and dried by suction for one minute longer than required to remove all surface moisture. The bottom of the meter was closed and 5% formalin added until the miniscus touched the needle-tip. The volume added from the 50ml burette was measured and subtracted

from 50ml. The meter was drained and 10ml of 5% formalin were added to wash the contents into a sample jar. A maximum of 15ml extra solution was used to completely rinse the stomach sample into a sample jar. The volume was then made up to 50 ml. From this known volume of sample a fixed aliquot (0.3ml) was extracted and placed in a squared slide well, sometimes termed a "Sedgewick--Rafter counting cell"(Guillard 1978) and the microplankton counted in 10 grid squares. Identification of plankton was made to generic level but, where possible, also to species. The frequency of occurrence of organisms in the samples analysed was recorded and converted to a percentage of all samples for that month's survey.

Sampling for macro-zooplankton will not be described here because they were not found in the stomachs as whole organisms. Only partly digested or broken parts of larger zooplankton were found with the microplankton. They were thus not counted on macroscale but were included in counts with the micro-organisms. For the same reasons they could not be weighed separately from the phytoplankton. Comparison of phytoplankton and zooplankton proportions in the diet, though not intended to be, were thus confined to numerical compositions.

(b) Sampling from commercial catches:

Stomach contents and fullness were recorded during bulk sample analyses of commercial catches according to the methods described

by Davies (1957) except that after 1980 contents were only crudely identified as to whether they contained 100% phytoplankton, 100% zooplankton or a ratio of each mixed. Stomach fullness was volumetrically graded according to whether the stomachs were "full","half-full", or "empty".

9. DIET COMPARED TO AVAILABLE FOOD

Each depth group (p36) of diatom samples was compared to fish gut contents in terms of species composition, frequency and relative abundance. Relative abundance is expressed here in terms of whether a species was numerically dominant, abundant, common or scarce (p36). Straight line regressions using the method of least squares were applied to compare the variances in relative proportions between organisms in the stomach contents and the composition of available food in the environment.

10. CATCH DATA ANALYSIS

Regular samples of the catches off Namibia are taken from the landings of anchovy at Walvis Bay by Sea Fisheries personnel. First a bulk sample is taken from the catch, then a subsample is analysed *inter alia* for age, gender, maturity, stomach fullness, and, if time permits, the stomach contents are analysed as described by Davies (1957).

The results of this sampling completed in the 1980-1985 period

are analysed (Section B.4) to show the seasonal totals of anchovy per half degree of latitude. The distribution of anchovy catches in relation to depth and distance offshore, as typified in the 1982 season, were mapped per half degree and in relation to the 10, 30, 50 and 100 fathom isobaths. Total monthly catches as well as the modal lengths were calculated per half degree of latitude for the winter fishery in 1985. These were mapped out together with the seasonal catch rates for each half degree.

The data on feeding were analysed relative to catch position to define any geographic limits to feeding frequency. In all 466 samples of 50 fish each were recorded in 20-mile grid-squares covering the period 1980 to 1985 in the months April to August, and in 1981 and 1982 research samples from January to March were also included. These were graded according to whether the sample was taken from a catch made in an "inshore", "nearshore", or "offshore" grid square and totalled for each degree of latitude. These categories were determined by whether the square was against the coast, 20-40 n.miles offshore or more than 40 n.miles off. The table represents the frequency per degree of latitude for samples obtained in which anchovy were found to have been recently feeding (ie guts more than half-full). Catches are routinely sampled thus reducing the possibilities of any bias and can be accepted as a fair reflection of the feeding distribution of anchovy off Namibia.

SECTION B : ANCHOVY DISTRIBUTION

RESULTS

B.1 ENVIRONMENTAL FACTORS

The oceanographic processes involved off the lengthy Namibian coastline have been fully described by Hart and Currie (1960), Stander (1962), Stander and De Dekker (1969), Visser *et al* (1973) O'Toole (1980), Boyd (1983a & b), Parrish *et al* 1983, Boyd and Agenbag (1985). Shannon (1985) and Shannon *et al*(1986) reviewed and updated the information available on the Benguela System as a whole. Also, O'Toole (1977), Badenhorst and Boyd (1981) and Le Clus and Kruger (1982) have related these processes to egg and larval distribution and survival. Boyd (1983a), Kruger and Boyd (1984), Le Clus and Kruger (1982) and Boyd *et al* (1985) have described the near-surface oceanography off Namibia for the same period as this study. The data collected during this study were mostly included in these studies as part of a multi-disciplinary analysis. Unpublished data collected at shoal-ecology stations found nothing contrary to the general findings of these studies occurred in the proximity of anchovy shoals studied. Thus, no attempt is made here to re-analyse oceanographic trends in the area. Only the general conditions during the study period will be outlined. Specific features reported by the above authors and pertinent to shoal distribution in this study will be discussed.

Kollmer (1958 and 1963), Hart and Currie (1960) Nel (1968), Visser et al (1973), Kruger (1980 & 1983), Austin (1980), Kruger and Boyd (1984) and Fearon et al (1986) have detailed the phytoplankton and zooplankton regimes off Namibia and the western Cape coast. A recent review was completed by Shannon and Pillar (1986). In this study I concentrate on my own findings and those features outlined by these authors which directly affect the environment and behaviour of anchovy off Namibia.

Figures 10-13 show a summary of the monthly distribution of phytoplankton and zooplankton averaged for 1981 to 1984, based on the same data described by Le Clus and Kruger (1982), Kruger (1983) and Kruger and Boyd (1984). The general pattern north of Walvis Bay is one of dense phytoplankton close inshore (up to 15 miles from the coast) with higher concentrations north of Cape Frio and localised offshore patches of dense phytoplankton mixed with zooplankton between Cape Frio and Cape Cross. Otherwise the offshore regions are dominated by zooplankton. South of Walvis Bay phytoplankton often extends much further offshore and normally forms denser concentrations inshore. Figure 14 illustrates the ratios of phytoplankton:zooplankton found in the 1981 summer, representing a typical situation. Good catches of anchovy adults and recruits prevailed but 1981 was not an exceptional year. An approximate line matching the zone of mixed zooplankton and dense phytoplankton was found to extend diagonally from roughly 50 miles offshore west of Hollams Bird Island to nearshore off

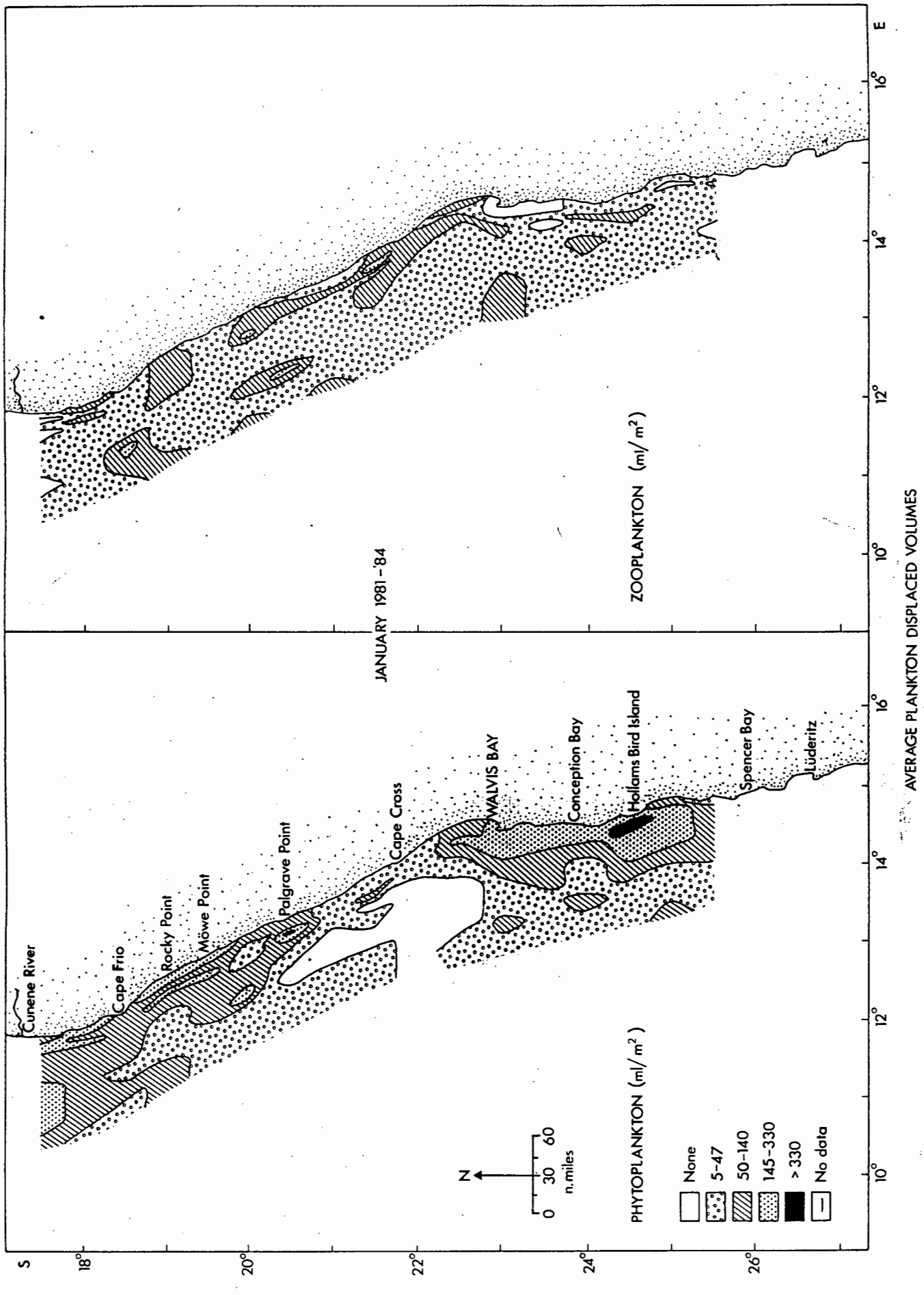


Figure 10 AVERAGE DISPLACED VOLUMES : PHYTOPLANKTON AND ZOOPLANKTON

JANUARY 1981 -1984

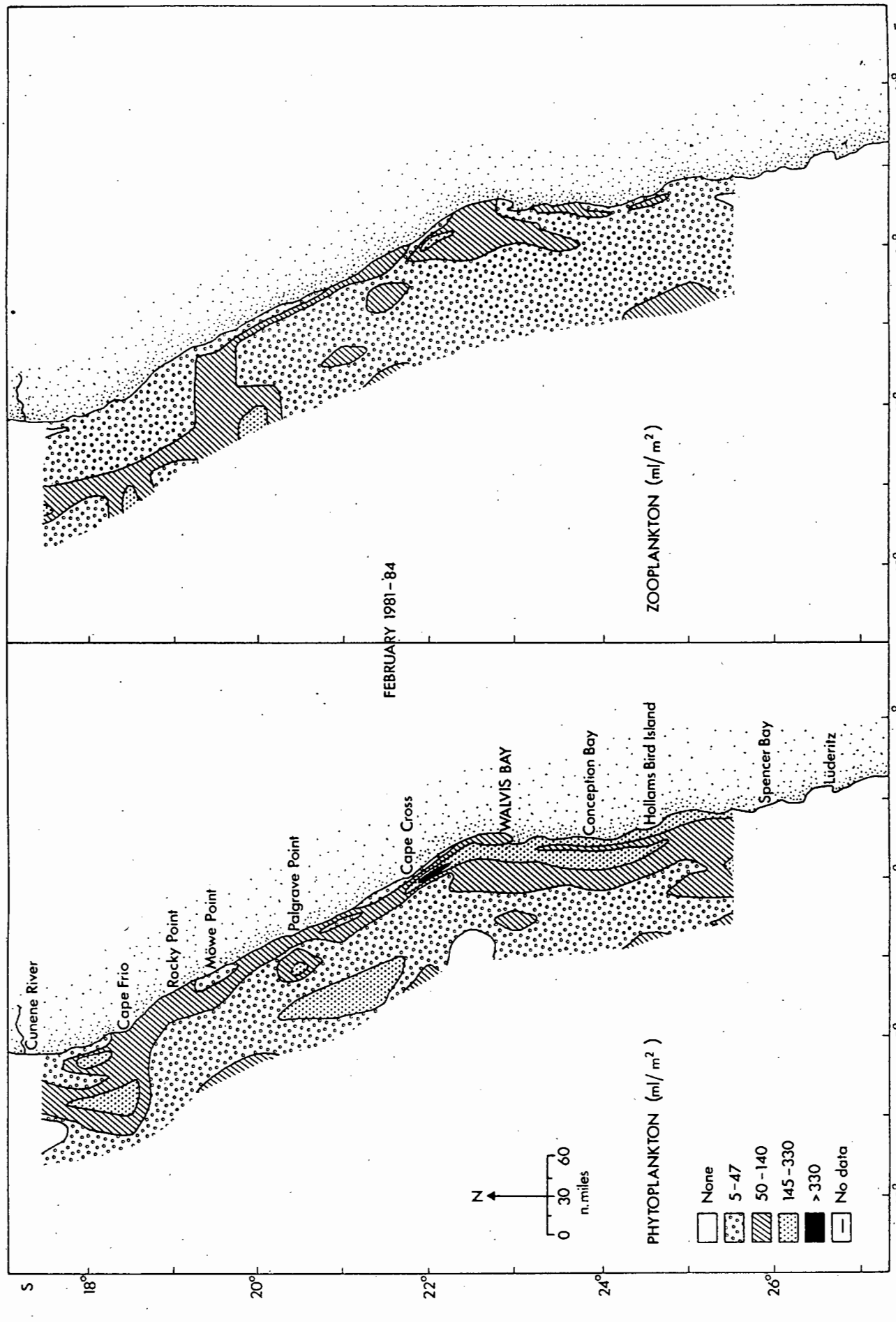


Figure 11 AVERAGE DISPLACED VOLUMES : PHYTOPANKTON AND ZOOPLANKTON, FEBRUARY 1981 -1984

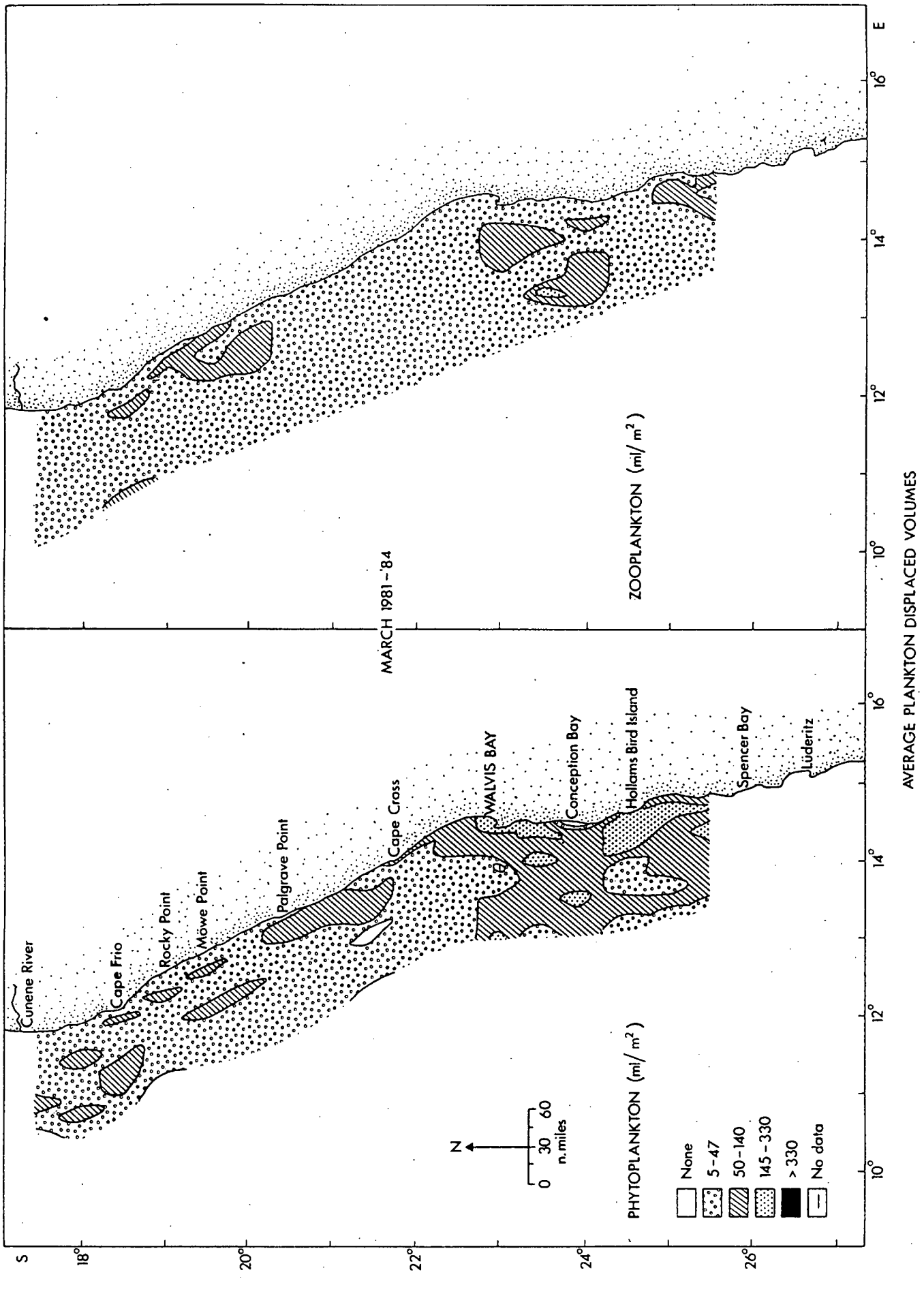


Figure 12 AVERAGE DISPLACED VOLUMES : PHYTOPANKTON AND ZOOPLANKTON, MARCH 1981 - 1984

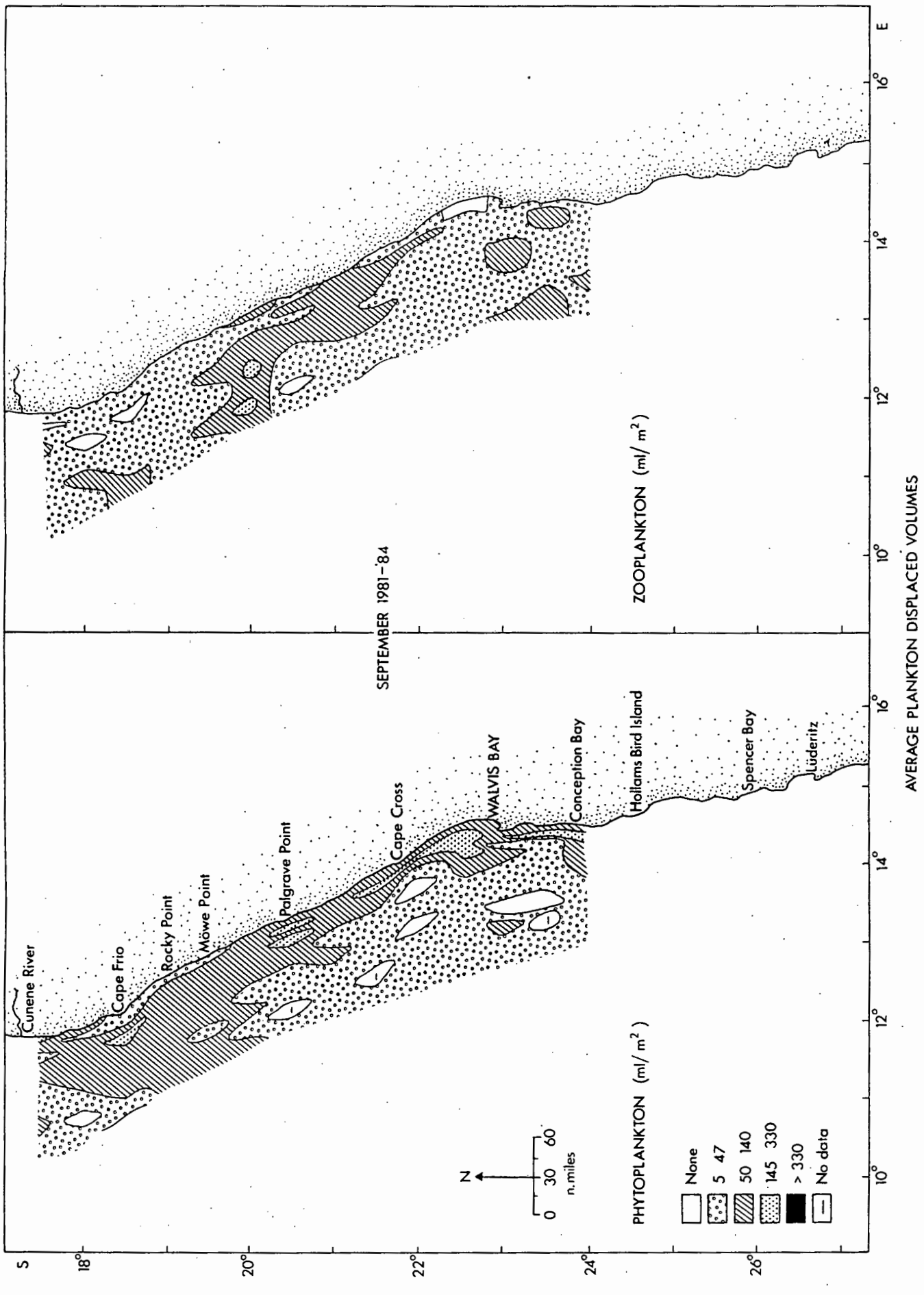


Figure 13 AVERAGE DISPLACED VOLUMES : PHYTOPLANKTON AND ZOOPLANKTON

SEPTEMBER 1981 -1984

Walvis Bay. In some years (e.g.1982) the phytoplankton abundance was relatively low (Kruger 1983) due to cooler than average temperatures (Boyd 1983), and the zooplankton extended closer inshore.

Strong upwelling is characteristic of the entire Namibian coast but is most intense around Lüderitz (Stander 1964; Shannon 1985). There is a substantial reduction in upwelling north of Walvis Bay. This has a profound effect on the concentration of phytoplankton and zooplankton. Fluctuations in the availability of planktonic food supply in turn affect the distribution of fish and survival of their larvae and early juveniles. Marked changes in some hydrological features such as temperature and dissolved oxygen content of certain water masses may also directly affect distribution and migrations of adult and juvenile fish (Cruickshank 1983b) as well as the growth rate and survival of juveniles (King 1977 and King et al 1979).

Temperature and salinity fluctuations in the upper 50 meters off Namibia are mainly governed by the extent and intensity of upwelling and mixing. The dynamics of upwelling and interaction between the cool, northward flowing Benguela current and the warm southward flowing Angolan current control the position and extent of seasonal intrusions and withdrawals of oceanic water between the Cunene River and Hollams Bird Island (O'Toole 1980). Close to the coast thermoclines are generally shallow, being 20

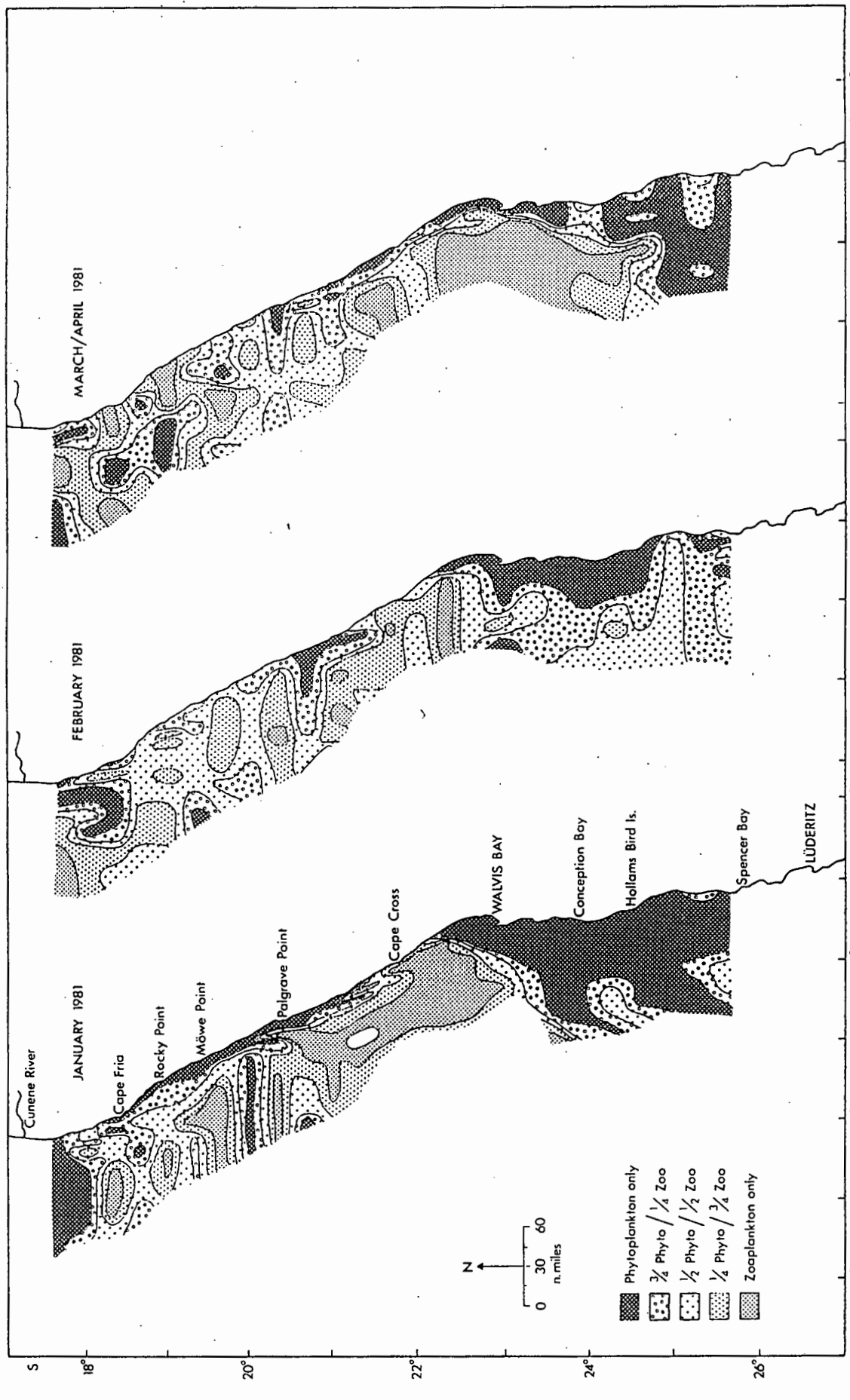


Figure 14 RATIO : ZOOPLANKTON TO PHYTOPLANKTON SUMMER - AUTUMN 1981

meters or less from the surface from spring to autumn (Boyd 1983; Cruickshank and Boyd 1985). They are most marked in late summer and early autumn when upwelling is weakest. In winter solar heating is reduced and in spring wind speeds increase, intensifying upwelling and disrupting the thermal gradients. Cool, well mixed coastal waters are thus characteristic of winter and early spring months (O'Toole 1980).

Currie (1953) and Stander (1962) noted two distinct surface water bodies relatively sharply divided between cold(<14°C), low salinity(<35.2°/oo), inshore waters and warmer(15-18°C), medium salinity(35.3-35.4°/oo), oceanic waters offshore. O'Toole (1980), however, described three main water masses. These were (1) cold (14°-18°C), low salinity (34.9-35.1°/oo), upwelled water occurring mainly in the southern region and moving northward with the Benguela current; (2) warm (17°-22°C), highly saline (35.5-35.9°/oo) Angolan current water off Cape Frio, periodically advancing south-east or retreating north-west. Incursions of this water are most pronounced in summer months and show substantial interannual variation according to Boyd et al (1987); (3) oceanic water of intermediate temperature (16°-20°C) and salinity (35.2-35.5°/oo) which usually advances from the west towards the coast between 19°S and 22°S. Greatest intrusions occur in summer and are also related to upwelling intensity near the coast. This water could be a result of mixing between Benguela and Angolan current waters.

Some authors have reported distinctive fluctuations in the above oceanographic regimes which can be closely correlated with large fluctuations in anchovy recruitment. Others have indicated the existance of southward flows at the surface besides the northward flowing Benguela Current. Stander (1964) showed that southward flow can occur north of 23°S. Yelizarov (1967) has also reported an offshore, southward flowing current 50 to 80 miles offshore at least between 23°S and 27°S. Nelson and Hutchings (1983) suggested a cyclonic gyre between 18°S and 25°S with southward movement against the coast while Moroshkin et al (1970, quoted in Boyd and Agenbag 1985) proposed southward flows between a complex of northward flowing filaments of the Benguela Current. Lütjeharms and Stockton (1987) and Shannon and Agenbag (1987) have described offshore eddies associated with large upwelling tongues between 23°S and 27°S. These could have an important bearing on nursery migrations of anchovy (Chapter B.5).

Boyd and Cruickshank (1983) described a basin model defined by variation of temperatures from the 12 year average at 20 n. miles offshore, using as baseline for each season winter(14°C) and summer(16.5°C), temperatures selected as favourable from areas of highest concentrations of fish shoals, eggs and larvae. Anchovy distribution (Cruickshank 1983a and b) consistently matched their "favourable basins" (19°-25°S) for winter and summer. Boyd and Cruickshank(1983) also described a minor basin for anchovy distribution off the Orange River area. This is separated from

the Namibian stock to the north and from the main Cape (RSA) stock to the south by a low temperature barrier (<13°C) which is strongest between Lüderitz and Chamais Bay. They found, however, that for anchovy it was possible for inflow to or southward outflow from this basin to occur in some months. This supports the findings of Cruickshank (1984 and this study) that juvenile anchovy occuring between Chamais Bay and the Orange River are not a static population but move southwards and probably recruit into the St. Helena Bay fishery.

Oceanographic trends relevant to fish distribution studies

During the study period (1978-1985) and also in 1972, series of general fluctuations in average temperatures, mostly attributable to incursions of warm water, were noted and these had marked effects on the anchovy population off SWA. Some examples are given below.

In 1971-1972 90% of shoals were recorded in a warm (16°C), surface counter current extending from the north past Walvis Bay (Visser et al 1973) but in June 1972 when an abnormally warm, surface counter-current dominated the upper 10 meters and caused strong thermoclines pelagic fish were recorded underneath this warm water in the cooler Benguela Current waters below (Visser et al 1973). In July 1978 the highest number of anchovy recruits recorded in the Walvis Bay area coincided with the short-term occurrence of water 3°C to 4°C warmer than average (Boyd and Baden-

horst 1980). During 1978/79 good, early anchovy spawning associated with warm conditions in the northern area was described by Badenhorst and Boyd (1981). The same authors also state that in July 1979 there was lower mid-winter recruitment (than 1978) when there was no intrusion of warm water. According to Boyd (1983) the 3°C lower-than-average temperatures in December 1979 caused a delay in peak spawning and the cool winter conditions associated with an absence of warm water intrusion in June and July 1980 led to a low recruitment in winter that year. He also described a good recruitment in 1981 following a warm water intrusion in June 1981 and poor recruitment following generally cold conditions and absence of a warm water intrusion in 1982. These cool conditions in the winter of 1982 were also described by Boyd and Agenbag (1985). By contrast, extremely warm (24°C) El Niño conditions in 1984 (more than 6°C above average) were followed by total failure of recruitment (Boyd et al 1985; LeClus 1985).

Abbreviated descriptions of environmental conditions from 1978-1985 are given below to stress patterns of salient features, such as warmer/cooler water conditions and their origins, which had an impact on the anchovy distribution recorded by the author.

1978/79:

Figure 15 illustrates the monthly distribution of surface temperatures for the summer of 1978/1979. Overlaid on the temperature isolines are shaded the areas of highest phytoplankton concentration according to LeClus and Kruger (1982) and Kruger

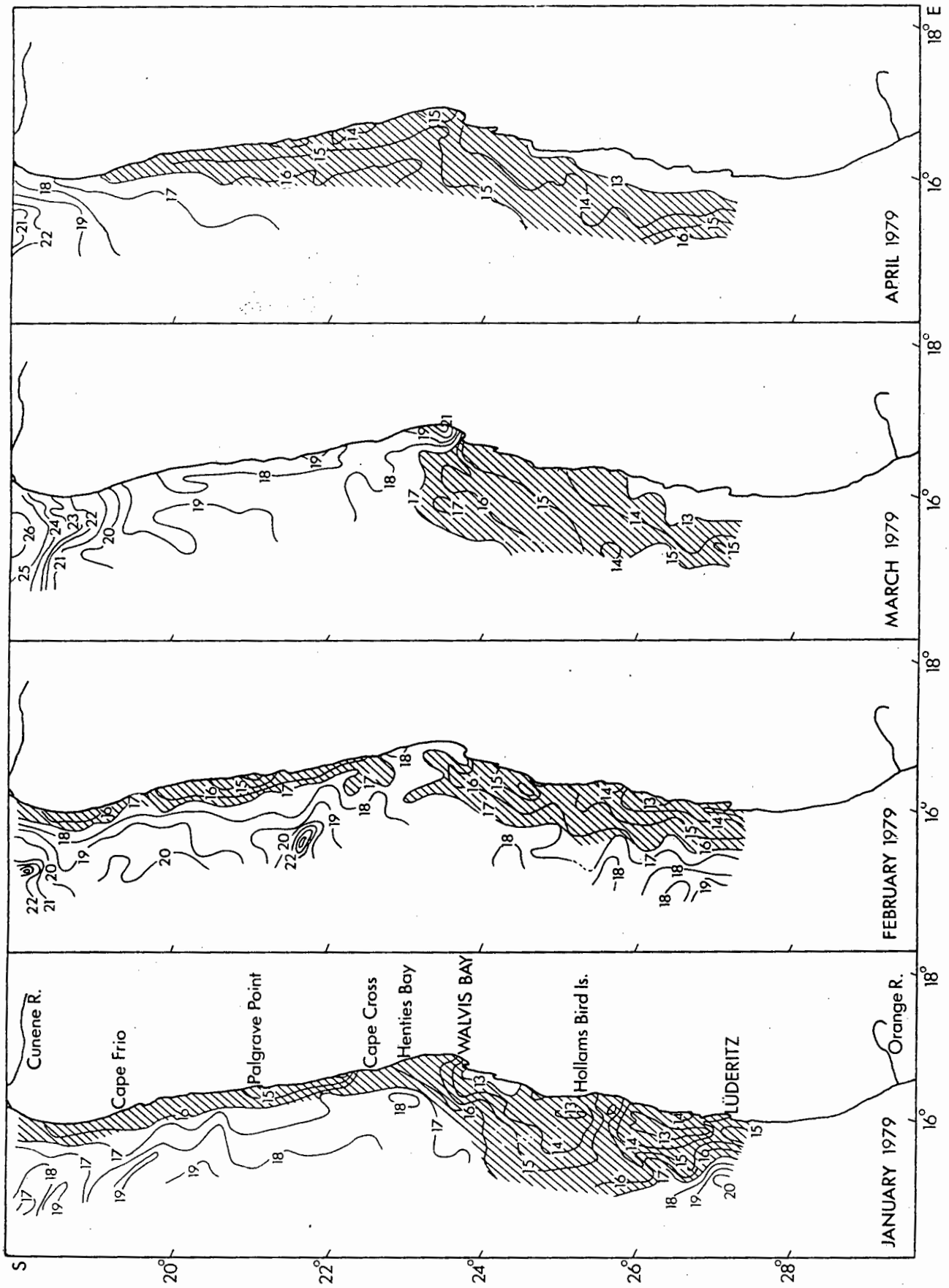


Figure 15 SURFACE TEMPERATURE DISTRIBUTION, SUMMER - AUTUMN 1979
Shading indicates the distribution of phytoplankton (>10ml/haul)

(1983). Comparison with summer distribution of anchovy found during acoustic surveys in the same months (Figures 22-24) shows a clear match between anchovy distribution and the optimal temperature range of 14-16°C described by Cruickshank and Boyd (1985) and with the plankton distribution.

1980:

During a July-August survey in 1980, conditions were found to be steady with cool (12.5°C to 15°C), well mixed waters with low salinity (± constant 35.2°/oo) and high oxygen levels (more than 4 ml/l) in the upper 20 meters. During this period anchovy recruitment was low as reported by Boyd (1983) and adult anchovies were highly clustered in dense shoal groups very close inshore off Durissa and Ambrose Bays and around Palgrave Point.

1981:

LeClus and Kruger (1982) described the 1981 summer hydrological environment off Namibia from the same SWAPELS/Hydroacoustic survey cruises that this study is largely based on. High salinity (35.5°/oo), warm (20°C) Angolan water penetrated as far as Walvis Bay by January 1981 but retreated to 20°S in February and to 18°30'S by March/ April. In February turbulence and upwelling increased and in autumn upwelling was widespread. The Angolan current had penetrated further south and for longer than in the previous year. A 20% increase in anchovy egg production was recorded in 1980/81 compared to 1979/80. Anchovy egg distribution usually coincided with dense patches of phytoplankton.

High density phytoplankton occurred all along the coast in a

narrow inshore strip between Cape Frio and Palgrave Point whereas south of Walvis Bay phytoplankton occurred over the whole survey area reaching up to 65 n.miles offshore. Dense patches occurred in February and March/April off Cape Frio, south of Palgrave Point and between Walvis Bay and Hollams Bird Island. Zooplankton distribution was patchy.

Autumn and winter conditions were characterised by cooler (12-15°C), low salinity (35.0°/oo) water extending as far north as Palgrave Point. Oxygen levels were high (>5 ml/lin the upper 20m extending to 50m in August but were confined to the upper 10m inshore (10 miles) between Cape Cross and Palgrave Point where evidence of warm, low salinity (<35.2°/oo) water persisted after the recession of a June intrusion of such water as far south as Sandwich Harbour.

1982 & 1983:

Apart from July, 1982 was characterised by cooler than average conditions from late autumn throughout winter (Boyd 1983). February was also important because of a sudden drop by between 1° and 2°C below the average temperatures (Boyd, 1983) which was credited with having possibly caused a high mortality of eggs and larvae in that month. That, and the cooler conditions in autumn and winter (Boyd 1983; McLain et al,1985) without an intrusion of warm water in midwinter (Boyd 1983) was considered the cause of the poor recruitment of anchovy off Walvis Bay in winter 1982 (Cruickshank 1983a). This occurred despite normal

spawning (LeClus 1983) and a large stock of spawning adults detected during the summer/autumn acoustic surveys. 1983 was also a generally cool year (Mclain et al 1985; Shannon et al 1986), but anchovy recruitment was apparently normal. There are no data on the distribution of fish during this period and so these trends will not be discussed further.

1984:

1984 was a disastrous year for the Walvis Bay anchovy fishery (anchovy having been the dominant species since 1978) and was characterised by spawning that was 20 times less than average (Le Clus 1985) and a complete recruitment failure for anchovy. This was attributed to an abnormally warm tropical water intrusion extending from the Cunene River past Walvis Bay as far as Hollams Bird Island (Boyd and Thomas 1984; Thomas and Boyd 1985; McLain et al. 1985). Water in the upper layers was as much as 6^{o}C above average. Over large areas plankton abundance in February, March and April was dramatically (4-10x) below average (Boyd et al 1985). Though no direct survey data on fish distribution were collected the commercial catch statistics show the impact on anchovy. Catches were displaced roughly 150 miles southwards (Thomas and Boyd 1985) such that adult anchovy were caught in the region of Walvis Bay and there was a total collapse in recruitment in 1984. This intrusion was thus, a major environmental event which drastically affected the anchovy population off Namibia.

1985:

This year is discussed in more detail, season by season, to match

data on the fish distributions detailed in Chapter B.3. The long-term average temperatures at 20 miles offshore, as described by Boyd and Agenbag (1985) are presented in Figure 16.

Summer: Average conditions prevailed in the summer of 1985 with anchovy occurring in waters ranging between 14°C and 20°C but densest in waters of 15-16°C. North of Cape Cross anchovy distribution corresponded to the isoclines of high chlorophylls (22 ug/l) but south of Walvis Bay the fish were detected in waters with low chlorophyll (<10 ug/l). Apart from effects of zooplankton grazing this low phytoplankton abundance south of Walvis Bay may have been due to upwelling close to the coast not allowing phytoplankton blooms to develop fully at the time of sampling. Dissolved oxygen values (6-8 ml/l) were generally high at the surface throughout the region.

Autumn: Cool conditions prevailed in March (Boyd et al 1987). Anchovy were detected less than 10 miles offshore generally corresponding to the 15°C isocline but not exceding the range of 16°C temperatures. Inshore oxygen values were moderate (3-4 ml/l) and chlorophyll values very high (>20 ug.at./l) among the anchovy shoals.

Winter: Between Palgrave Point and Cape Cross water cooler than 15°C with low salinities occurred in May. South of Cape Cross water temperatures nearshore, where anchovy occurred were lower (generally 14°C) but oxygen values remained high (5-8ml/l). These oxygen values clearly indicated upwelling between 22°S and 24°S.

In June, temperatures in the upper 20 meters continued to

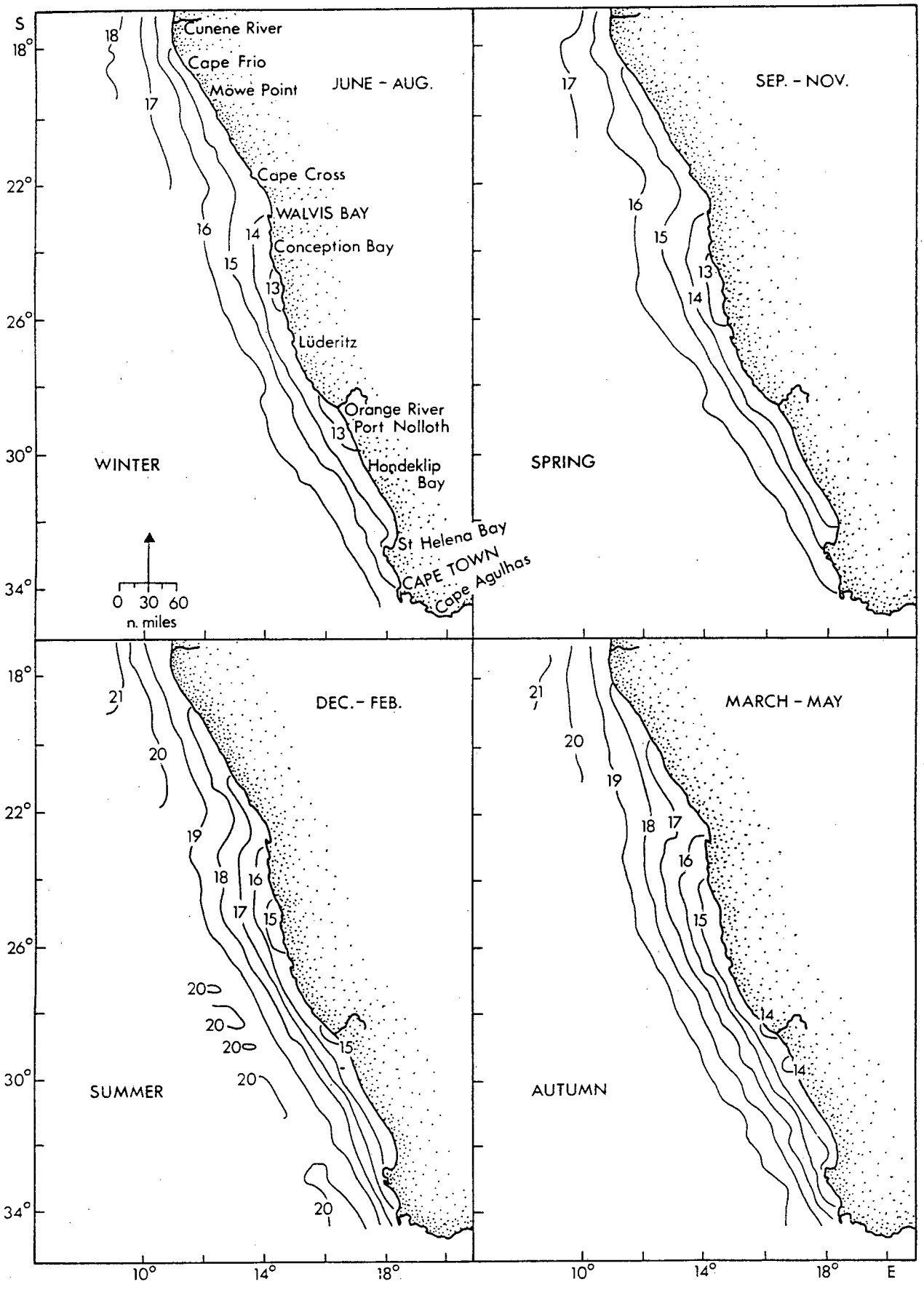


Figure 16 AVERAGE WEST COAST SEASONAL TEMPERATURES (Boyd & Agenbag)

decline. The inshore waters south of Conception Bay were less than 13°C with 14°C water only present more than 35 n.miles offshore. North of Conception Bay inshore waters as far as Dune Point were 13°C while 14°C water dominated the midshelf region as far as Rocky Point. Waters at 15°C and 16°C were only present beyond 35 and 50 miles respectively. Low oxygen values (<3ml/l) down to 20m depth accompanied the low temperatures inshore between Ambrose Bay and Conception Bay. North and south of this area high values (4-6 ml/l) occurred inshore and offshore (15-35 miles) along the whole coast. July and August were also dominated by cool (13-14°C), low-salinity(<35.2°/oo), high-oxygen(>5 ml/l) waters.

The favourable, average conditions in the summer months were thus reversed by long-lasting, cooler-than-average conditions throughout the region during the autumn and winter of 1985. This is similar to the conditions in 1982 (February excepted) and almost certainly had the same negative effect on anchovy recruitment. In 1985 the recruitment was "good" compared to the very poor years in 1983 and 1984 but, overall, considering the data since 1978 it was also a year of lower recruitment. The recruitment catch after June (41 000 m.tons) was virtually the same as that landed in 1982 when the midwinter warm intrusion failed to occur so that temperatures were 1°-2°C below average and phytoplankton and zooplankton availability were lower than average (Kruger 1983) at a time when they would have been most needed for larval and early juvenile survival in late summer and autumn. These

factors were suggested by Cruickshank (1983a) to have caused higher mortality and poor recruitment. It appears that a similar set of conditions may have prevailed in 1985.

This study did not investigate (broad-scale) plankton community structure but it is vital that such be conducted relative to the ocean current systems in the region (Figure 42). An in-depth understanding of changes in the plankton communities could provide valuable information on the actual links between the oceanographic processes and the year-class strengths of pelagic fish, in addition to their influence on migration patterns.

SUMMARY

Details of some environmental features from the summer of 1978/79 to 1985 are given. Shelf waters were generally dominated by temperatures ranging between 14°C and 18°C in summer and between 13°C and 16°C in winter months. The waters within 20 miles of the coast also contained highest densities of phytoplankton although in the more offshore waters, especially to the south, mixtures of up to 50 per cent zooplankton to phytoplankton occurred (Figures 10-15): conditions favoured by juvenile anchovy. The most successful recruitments, in terms of the fishery landings at Walvis Bay, were achieved in years when moderately warm water occurred in June or July off Walvis Bay and when the effect of the southward Angolan Current intrusion was relatively strong in summer, but not abnormally so, as in 1984. These slightly warmer

than average conditions favour the recruit fish which, in their early development, depend on stable temperatures of 16^0-18^0C and an abundant supply of mixed plankton. The timing of these features may be critical. If they occur simultaneously with the early juvenile and recruit anchovies they can promote the feeding and rapid growth phases of the young fish. The water temperatures and plankton densities are controlled by a variable regime of the cool Benguela Current, warm Angolan Current, intermediate oceanic water intrusions and upwelling. Thus anchovy recruitment appears to depend on large-scale oceanographic processes (Figure 42). Dissolved oxygen and nitrate are not readily correlated with anchovy distribution patterns but are nonetheless important indicators of the processes (such as upwelling and phytoplankton production) taking place within various water bodies. Salinity is important for understanding the identity and movement of the above water bodies which can affect anchovy recruitment not only through temperature and plankton productivity but also by providing the means for passive migration of, for example, spawning products.

B.2 SHOAL DISTRIBUTION IN SOUTHERN NAMIBIA

A major development at the beginning of this study (Butterworth 1980) was the discovery in December 1978 (Cruickshank 1979) of a substantial stock of anchovy shoals in the southernmost waters off Namibia, extending into RSA waters to roughly west of Hondeklip Bay. Though further evidence indicated a southward movement between Chamais Bay (28°S) and Hondeklip Bay (30°40'S) this group of shoals was consistantly detected during surveys of the region from December 1978 monthly to May 1979 (Figure 17a). A purse-seine trawler was used in some months from the Olifants River northward to identify these shoals. In addition characteristic shoal behaviour and bioluminesent patterns (Hampton 1974) were also used. Thereafter, this shoal group was recorded (Figures 17b & c) in June and August 1979, February, March/April, June and September /October 1980; September 1981; February and March 1982; April 1983 (Figure 18); June 1984 and in January, February, March and June 1985. A few commercial catches in the area were also recorded in 1984 and 1985 and some boats searched the area in May 1986 but only found loose shoals of juvenile fish.

The discovery and further survey of this subsidiary stock of anchovy, midway between the lucrative pelagic fishery stocks of the RSA and Namibia, provoked a number of interesting questions (Cruickshank 1979 & 1980, internal reports) about the constancy, stock size and origin of this sub-stock and its significance to the Namibian and Cape stocks. Grant(1985) found no major genetic

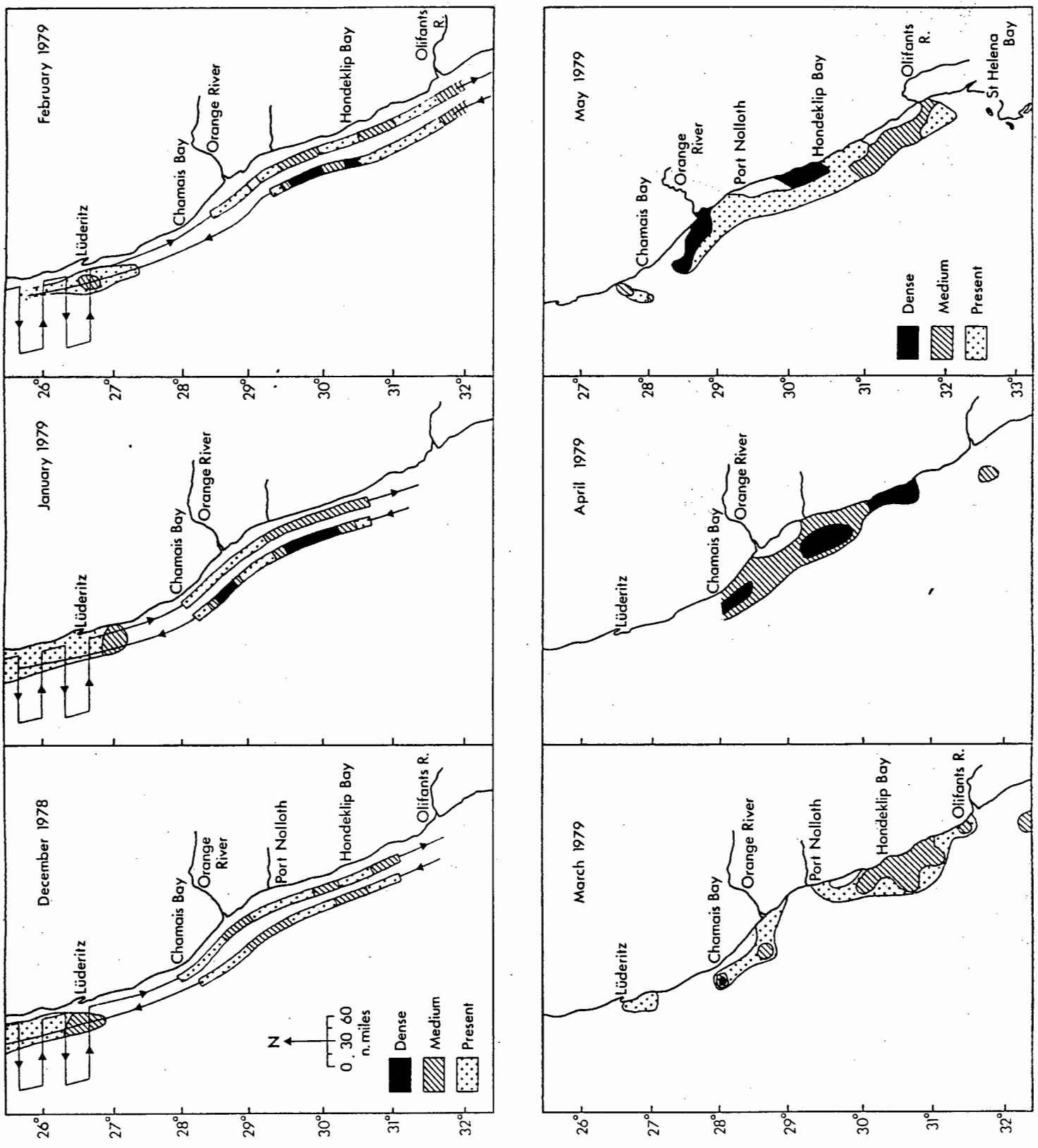


Figure 17a ANCHOVY DISTRIBUTION IN THE ORANGE RIVER AREA, 1978/1979

December to February show distribution detected in transits parallel to the coast whereas March to May show distribution detected during grid surveys with a catcher vessel.

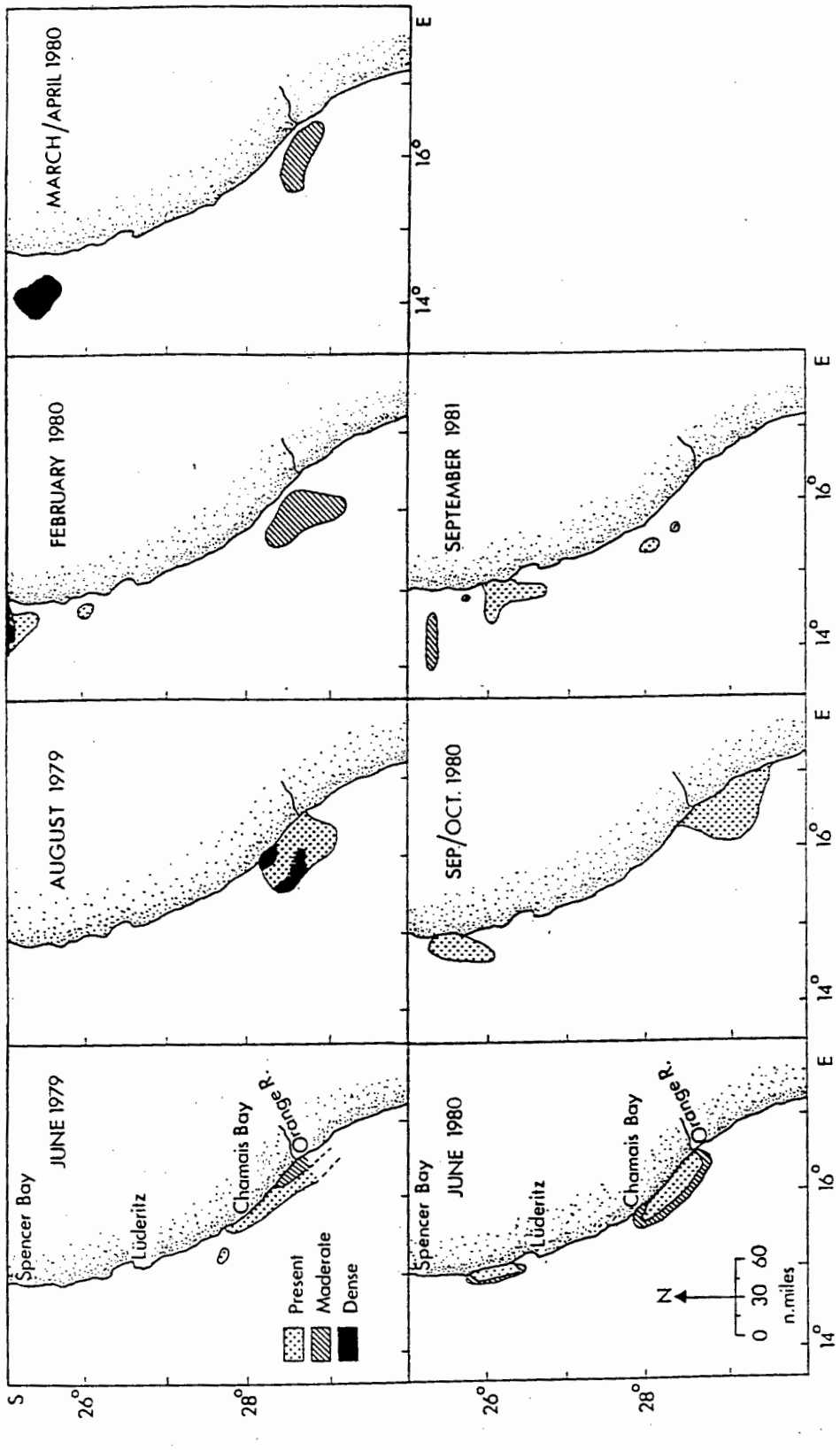


Figure 17b ANCHOVY DISTRIBUTION IN THE ORANGE RIVER AREA, 1979/80-1981

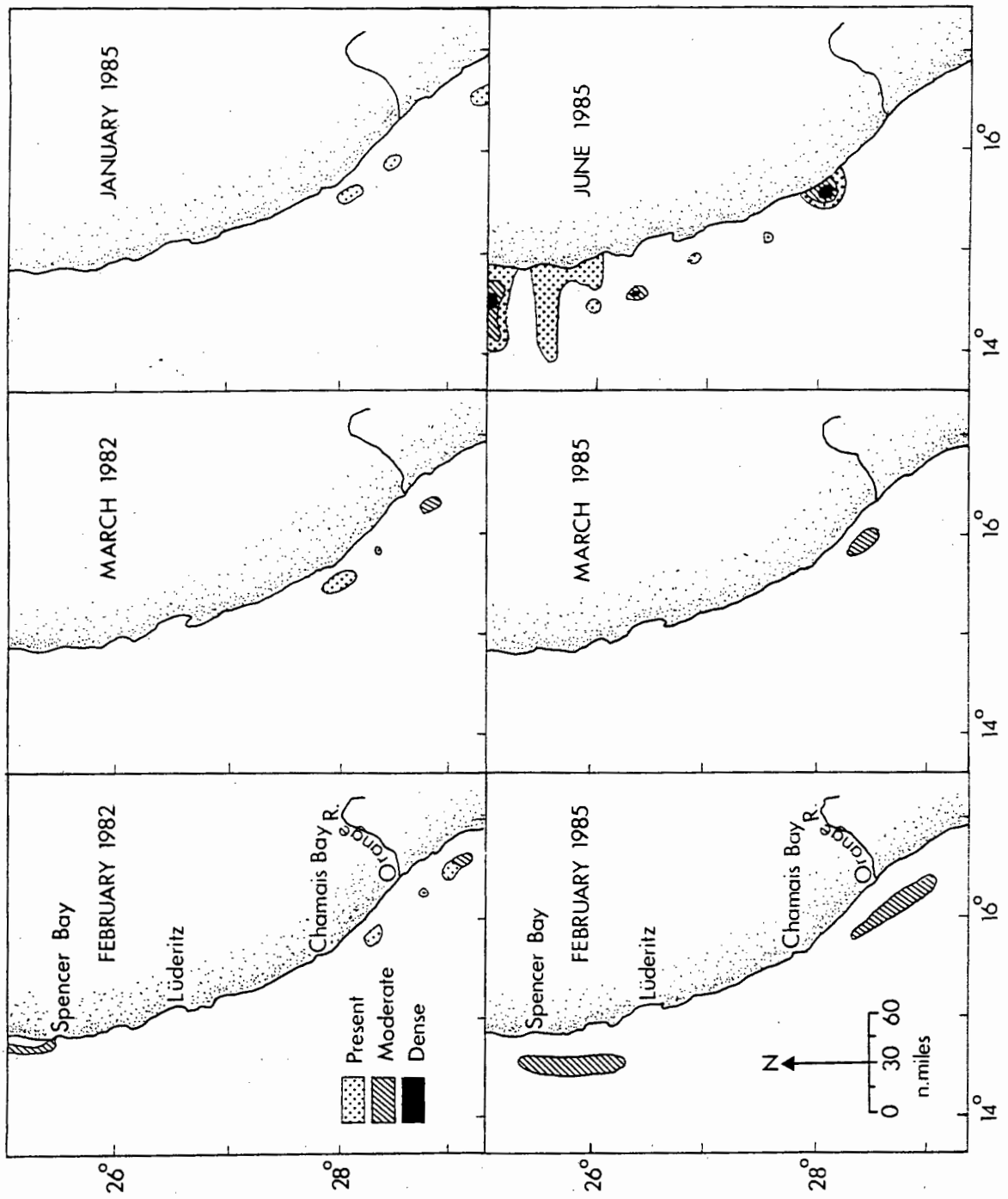


Figure 17c ANCHOVY DISTRIBUTION IN THE ORANGE RIVER AREA, 1982-1985

differences between the populations off the Cape, Orange River and Namibia. After the initial surveys in 1978/79 this sub-stock was estimated to be in the order of 20-50 thousand metric tons for the whole area from Chamais Bay to the Olifants River (31°40'S) based on shoal size and density. Accurate estimates of this isolated anchovy stock together with those around the Cape are being developed through further, quantitative acoustic surveys by the Sea Fisheries Research Institute (Hampton and Armstrong, in prep.). Though fairly consistantly present somewhere between Chamais Bay and the Olifants River, these shoals are subject to large fluctuations in density and can be very mobile, travelling extensive distances southward past the Orange River and Port Nolloth.

In June 1979 shoals were detected off Kerbhuk (28°20'S, just north of the Orange River) during the northward passage of a survey cruise. The shoal group was noted to be much reduced from that recorded up until April 1979. A group of five fishing boats recorded small shoals from Kerbhuk to the Orange River. On the southward journey of the research ship, shoals were not detected north of the Orange River but were detected between Kleinsee and Hondeklip Bay. There is no evidence directly linking these two recordings of shoals. However, it is not beyond the capabilities of the fish to move this far, and later evidence supports the possibility. Samples in March and April 1979 yielded only immature (8.0 cm) fish.

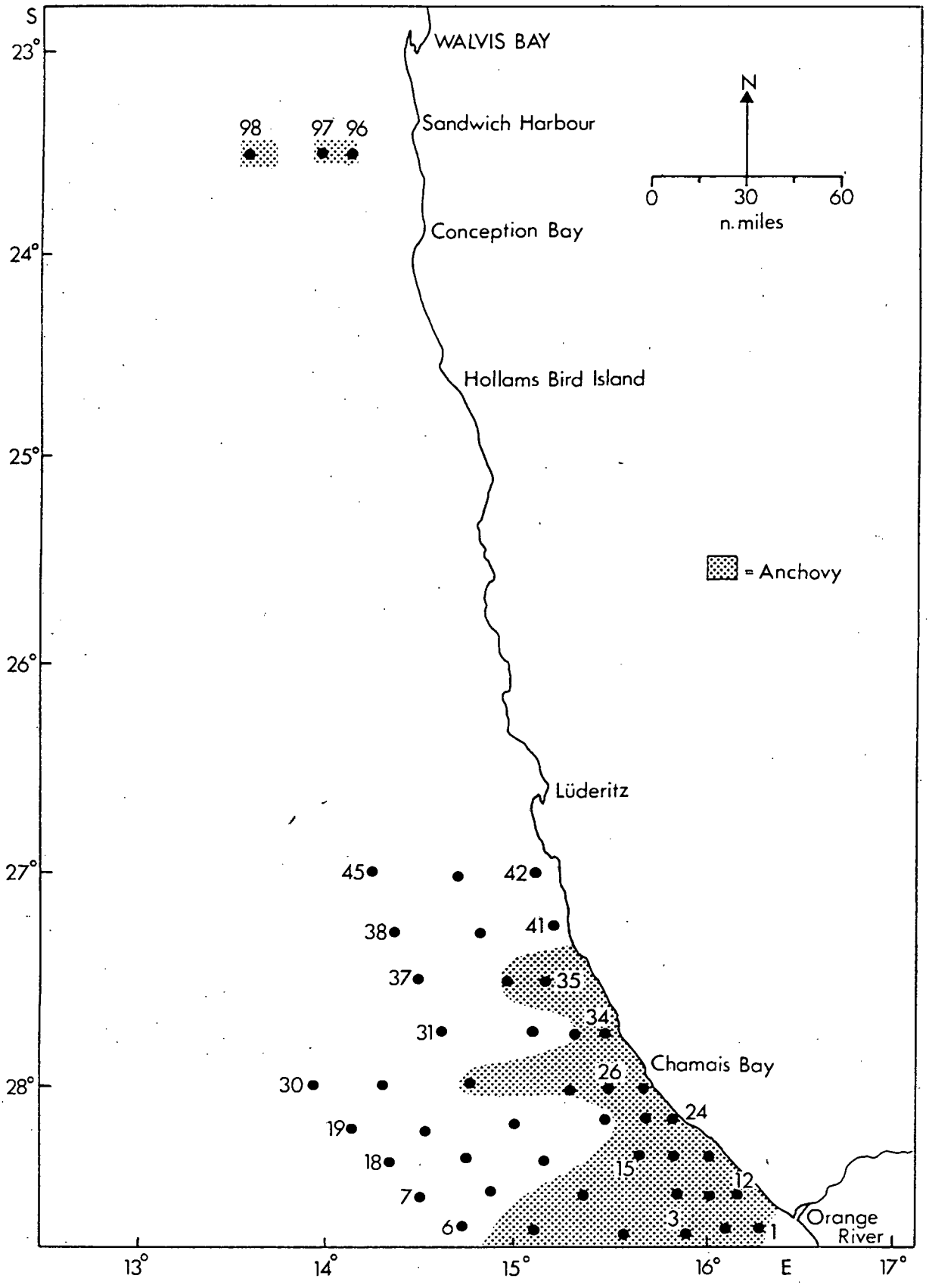


Figure 18 ANCHOVY DISTRIBUTION SOUTH OF WALVIS BAY, APRIL 1983
Only stations corresponding to the anchovy distribution are shown

In April 1983 an intensive study of anchovy distribution was conducted from south of the Orange River to Walvis Bay (Cruickshank 1984). The distribution of anchovy shoals is presented in Figure 19. Shoals of anchovy juveniles were present up to 30 miles from the shore between the Orange River and Chamais Bay. These shoals were small and widely scattered. A large group of shoals of anchovy juveniles was found in open scattering layers at the surface, mainly close inshore off Panther Hill. All shoal targets were detected within the upper 30 m. between 1700 and 0100 hours. No targets were detected during daylight hours. No sign of any significant anchovy shoals were detected between Chamais Bay and Walvis Bay but a few juvenile anchovy were netted 15 miles west of Sandwich Harbour.

Length frequencies for each station are plotted against latitude in Figure 19. Modal standard lengths of anchovies caught at the various stations ranged from 4.5 to 6.5 cm but samples included a range of sizes from larval (15 mm) to adult (10cm). The length frequency reveals an absence of smaller larvae (except one 15mm larva at station AR-27). Considering that a similar pattern was obtained for both the RMT nets as well as the neuston net, it is unlikely that escape or net avoidance by smaller juveniles and larvae was responsible for this trend. It is suggested that the absence of small larvae indicates that the larvae were spawned elswhere and advected into this area. Hence, the presence of only prerecruits and a few late-stage larvae.

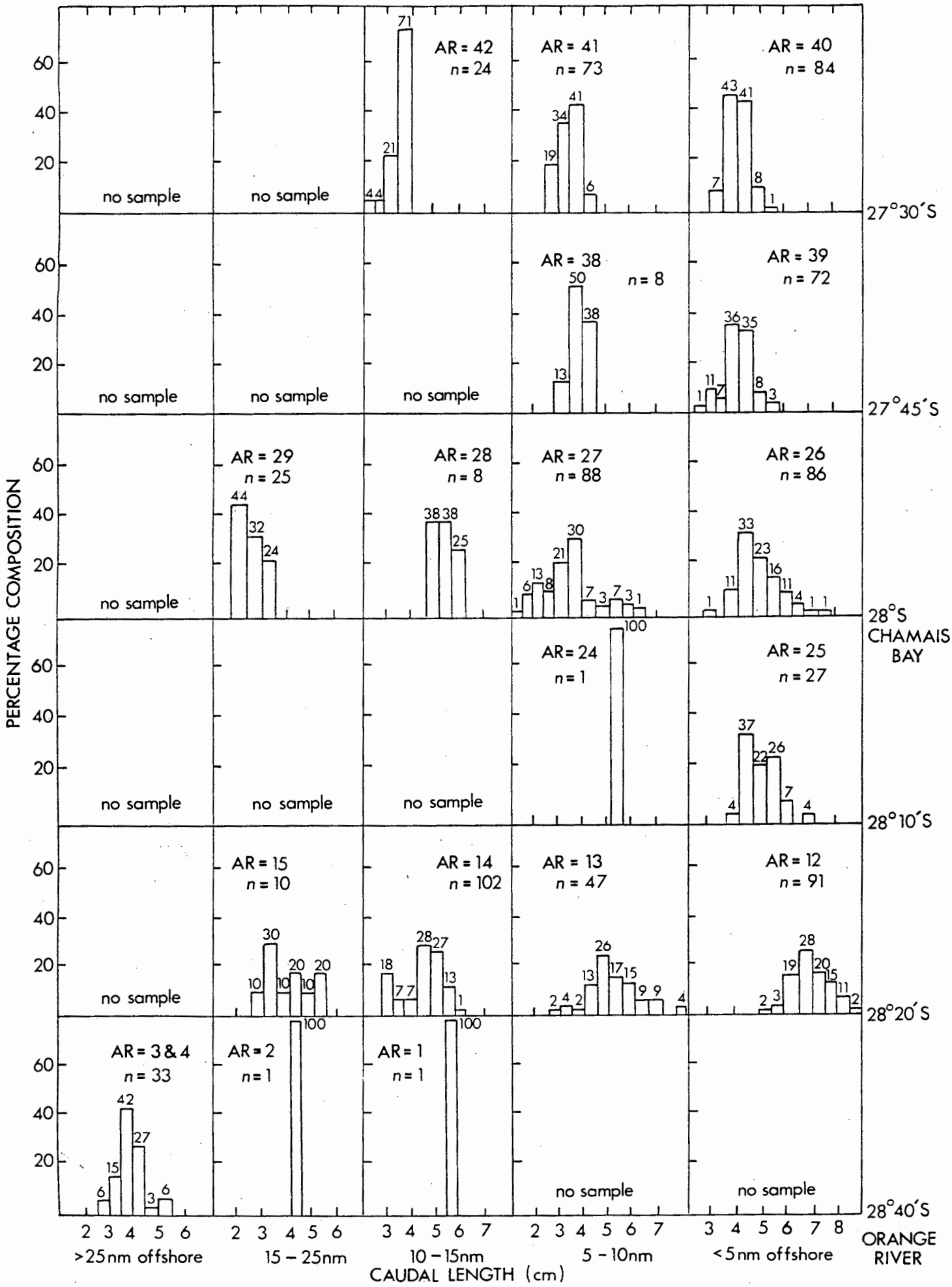


Figure 19 ANCHOVY LENGTH DISTRIBUTION ORANGE RIVER, APRIL 1983

Most of the larvae less than 30 mm long were caught 10 - 25 miles offshore. This, and the tendancy of the length frequencies to increase inshore and southward towards the Orange River, suggests an inshore and southward movement of these juveniles. During the return journey attempts to relocate and resample these shoals failed. One week later, in May, a similar acoustic survey conducted from the Orange River south to Cape Point found juvenile anchovies of corresponding size classes off Hondeklip Bay and further south (Hampton, pers. comm.).

The majority of all positive stations (for anchovy) were inside 25 miles, with a peak (70%) within 15 miles offshore (Figure 19). Pooling all the samples for a given degree of latitude, regardless of distance from shore, shows a shift in the modal peak from 35 to 45 mm, in a southward progression. A second mode at 65 mm (Lc) also appears towards the south. In the vicinity of Chamais Bay the phytoplankton distribution closely matched the distribution of the anchovy recruits. The commonest diatoms in water samples (Tables 13-15) corresponding to the distribution of these shoals were the same as those which dominated the gut contents and the water samples from other areas off Namibia (Section C).

Temperatures at the surface and at 25 m (maximum depth of shoals) for all the anchovy catches are plotted against latitude in Figure 20. All the shoals occurred at or well above the 14°C isotherm chosen by Boyd and Cruickshank (1983) to define their

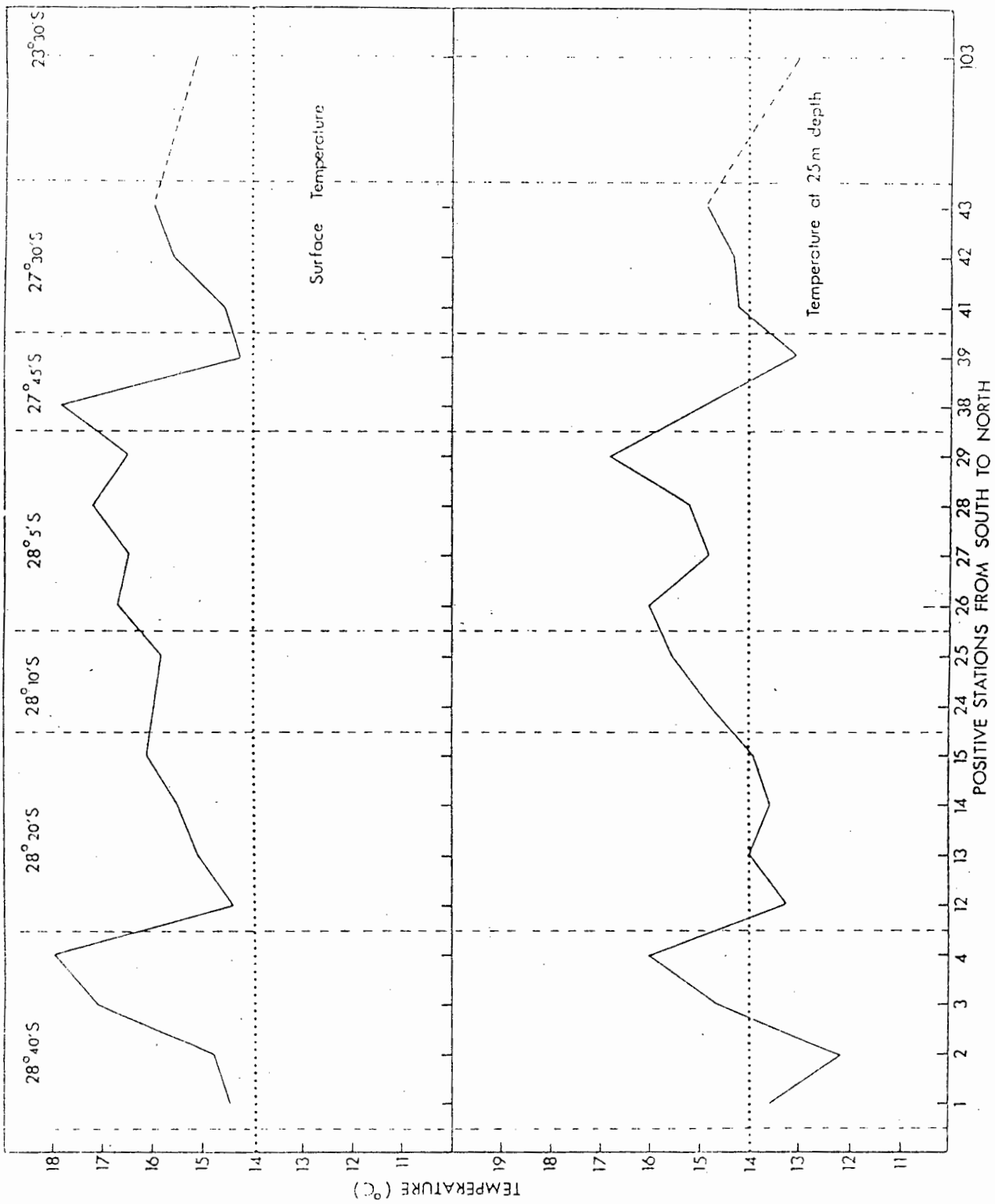


Figure 20 TEMPERATURES AT 0 & 25m FOR ALL STATIONS WHERE ANCHOVY WERE CAUGHT, APRIL 1983

Although temperatures at 25m depth for some stations were below 14°C, anchovy shoals all occurred above or at this temperature. Latitudes are indicated above and station numbers below on y-axis.

environmental basins for autumn and winter. When length distributions were compared to temperature, a distinct predominance of early juveniles (20-50 mm) was found at temperatures between 15,5° and 17,0°C, with greatest abundance at 15,5° and 16,5°C. In contrast, older specimens (60-85 mm) were collected at 14,0°C, which is in keeping with the trend towards an inshore movement as length increases. No juveniles were found at temperatures above 18,0°C or below 12,5°C. The cold waters of less than 13,0°C from north of Chamais Bay to Ichaboe Island apparently formed an effective barrier to the shoals moving in that direction. South of the Orange River, a subsequent survey found scattered shoals in 13°-15°C water displaced offshore near Hondeklip Bay by very cold, upwelled water inshore (Armstrong and Hampton, pers. comm.). Regular surveys in previous years (Figures 17a-c, & 25-31), covering the coast from the Olifants River to beyond Cape Frio, have consistently shown the apparent barrier to fish distribution between Chamais Bay and the Lüderitz area (Cruickshank 1983a)

In his documentation of the pelagic fishery for anchovy from South Africa, Crawford (1981) records a past history of intermittent shoals fished in the Orange River to Hondeklip Bay area. In 1965, 1966, 1967 and 1969 irregular patches of juveniles were caught between May and August either off the Orange River or more to the south between the Orange and Olifants Rivers. Catch rates were generally low. In February and March 1971 large catches were made between the Orange River and Port Nolloth. In

May and June the same year small catches were made further south between Port Nolloth and the Olifants River. Again, in March and April 1972, shoals of juveniles were caught between Port Nolloth and the Olifants River. Finally, in February 1974 very high catches of adults (Crawford considered fish more than 9.0cm as "adults") were made between Port Nolloth and the Olifants River and in March and April juveniles were abundant in the same area.

DISCUSSION

Surveys from 1979-1982 regularly detected anchovy shoals between Chamais Bay, just north of the Orange River, and the Olifants River. Crawford (1981) records a past history of intermittant shoals fished in the Orange River to Hondeklip Bay area from RSA ports. Viljoen (1983) describes the "sojourn" of anchovy shoals in the area prior to an initially slow movement southwards. He also reports abundant pre-shoaling anchovy juveniles in the Orange River area behaving similarly to the pre-recruit shoals off Walvis Bay. Thus, these shoals are a fairly permanent feature but are variable in quantity. This is in accord with a component dependent on advection of spawner products from other areas by some environmental feature having annual variation in penetration, such as the Good Hope Jet around the south-western Cape. This feature has been described by Bang (1973) and Bang and Andrews (1974), and its consequential effects on anchovy distribution described by Shelton and Hutchings (1982) and Badenhorst and Boyd

(1981). The larval size distribution patterns found by Badenhorst and Boyd (1981) led them to suggest a larval drift to Namibia from Cape waters carried by the Agulhas and Benguela Currents. Boyd and Hewitson (1983) described larval size distribution and frequency between Cape Columbine and Lüderitz from which they also concluded a southern origin of larvae but showed a shoreward increase in larval length up the West Coast. Cruickshank (1984) described length distribution of larvae, post-larvae and juveniles from the Orange River to Walvis Bay. His data concurred with the foregoing and suggested a movement towards the coast from offshore stations by the developing post-larvae and juveniles. He also showed an increasing size trend inshore down the coast past the Orange River suggesting a southward migration. This appeared to be supported by subsequent survey observations of shoal movements.

Boyd and Cruickshank (1983) described a minor geographical "basin" favourable for anchovy off the Orange River which could allow movement to the south. Cruickshank (1984) concluded that larvae collected near Walvis Bay form part of a distinctly different length mode to those much further south near the Orange River. Given this and the increasing evidence of a temperature barrier of cold water in the Lüderitz region (Boyd and Cruickshank 1983; Cruickshank 1983a&b; Cruickshank et al 1980; Shannon 1985), it is reasonable to assume that the juveniles off the Orange River belong to a different spawner stock to those off Walvis Bay.

Recent assessments of the RSA anchovy stock have not only confirmed the scenario presented here but have also shown that this is a more important component of the RSA stock than was previously recognised (Hampton and Armstrong, in prep.). In February 1987 these authors recorded many small shoals of anchovy juveniles (4-7cms) and late stage larvae, mostly in 12-14°C water outside a coastal band of cold upwelled water, from Hondeklip Bay to the Orange River. They interpret the strong 1987 recruit year class has having been entirely derived from the larvae advected into the Orange River area (Hampton and Armstrong, pers comm.). This compares favourably with the situation in the 1979/80 summer and winter when vast shoals were recorded in the area (Cruickshank 1980; Butterworth 1980). According to Hampton (1987) anchovy shoals between Chamais Bay and the Orange River in May/June 1985 amounted to a density of 20-50 tons/km^2. He also concluded that recruit anchovy on the West Coast migrate southwards as inferred by Crawford (1981), Viljoen (Anon. 1983) and Cruickshank (1984).

De Dekker (1970) has described an inshore, southward counter-current down the entire West Coast and Nelson and Hutchings(1987) have discussed how coastally trapped baratropic shelf waves could be responsible for southward advection of shoals of recruit fish along the west coast especially in the St Helena Bay area. But, we urgently need to know more details of the oceanography of the Orange River region to explain the mechanisms by which larvae entrained from the Agulhas area are caught up and held once

advected into this area.

The most obvious feature of this relatively featureless coastline is the Orange River with its wide, sediment-laden shelf. South from the Orange River to the Cape Canyon is a fairly level bottom, with light sediment deposition from the Orange River (Birch et al 1976, Rogers 1977). Around the Orange River mouth the shelf is much wider and shallower (10-50m) due to river effluent. From the Orange River to Lüderitz the shelf has little sediment deposition and falls away steeply, with a marked indent towards the coast south of Lüderitz (Bang 1971, Bang and Andrews 1974, Birch *et al*. 1976, Rogers 1977, Bremner 1978). This feature is sufficient to cause a marked baroclinic jet north-eastward and shoreward west of Chamais Bay with a high ambient speed of 30 m/sec. (Bang 1973, Bang and Andrews 1974). This provides a resultant intrusion of oceanic waters close to the coast on the poleward (south) side of the Lüderitz upwelling cell (Stander 1964, Bang and Andrews 1974). Inside of these anti-cyclonic intrusions there are probable eddies which further draw oceanic water against the coast off Chamais Bay (Bang 1971, 1973). Over the Orange River delta the influence of the inshore, poleward counter-current (De Dekker 1970, Bang and Andrews 1974) is dominant (Rogers 1977).

Current evidence thus suggests that although the Orange River delta area is oceanographically quiescent, around Chamais Bay

there is an interface with a very strong regime of hydrographic flows and wind stresses which are strong enough to prevent major sedimentation until north of Lüderitz but may help to accumulate it at the extremities of this area (Birch et al 1976, Bremner 1978). Therefore it is obvious that ichthyoplankton transported in the pelagic zone of the Benguela System will also be markedly affected by the current regimes between the Orange River and Lüderitz. It is then reasonable to expect that the northward drifting larvae will be strongly drawn in shorewards and accumulated off Chamais Bay. The area between Chamais Bay and Orange River may thus be a nursery area for at least some of the larvae spawned off the South and Southwest Coasts and carried round the Cape to West Coast nursery areas (Shelton 1979; Shelton and Hutchings 1982). From this nursery area pre-recruits move southwards under the influence of baratropic waves (Nelson and Hutchings 1987). Because there is a southward increase in size towards the Orange River (Cruickshank 1984) and an almost complete absence of adults taken by the commercial fisheries in the area (Crawford 1981, Schülein 1986) and in survey samplings, it is suggested that shoals of these young anchovy ultimately recruit to the St Helena Bay fishery. These shoal groups are thus not a truly Namibian stock but, a component of the South African stock around the Cape.

Figure 21 summarises the foregoing discussion and references therein. It illustrates the movements of the Orange River component

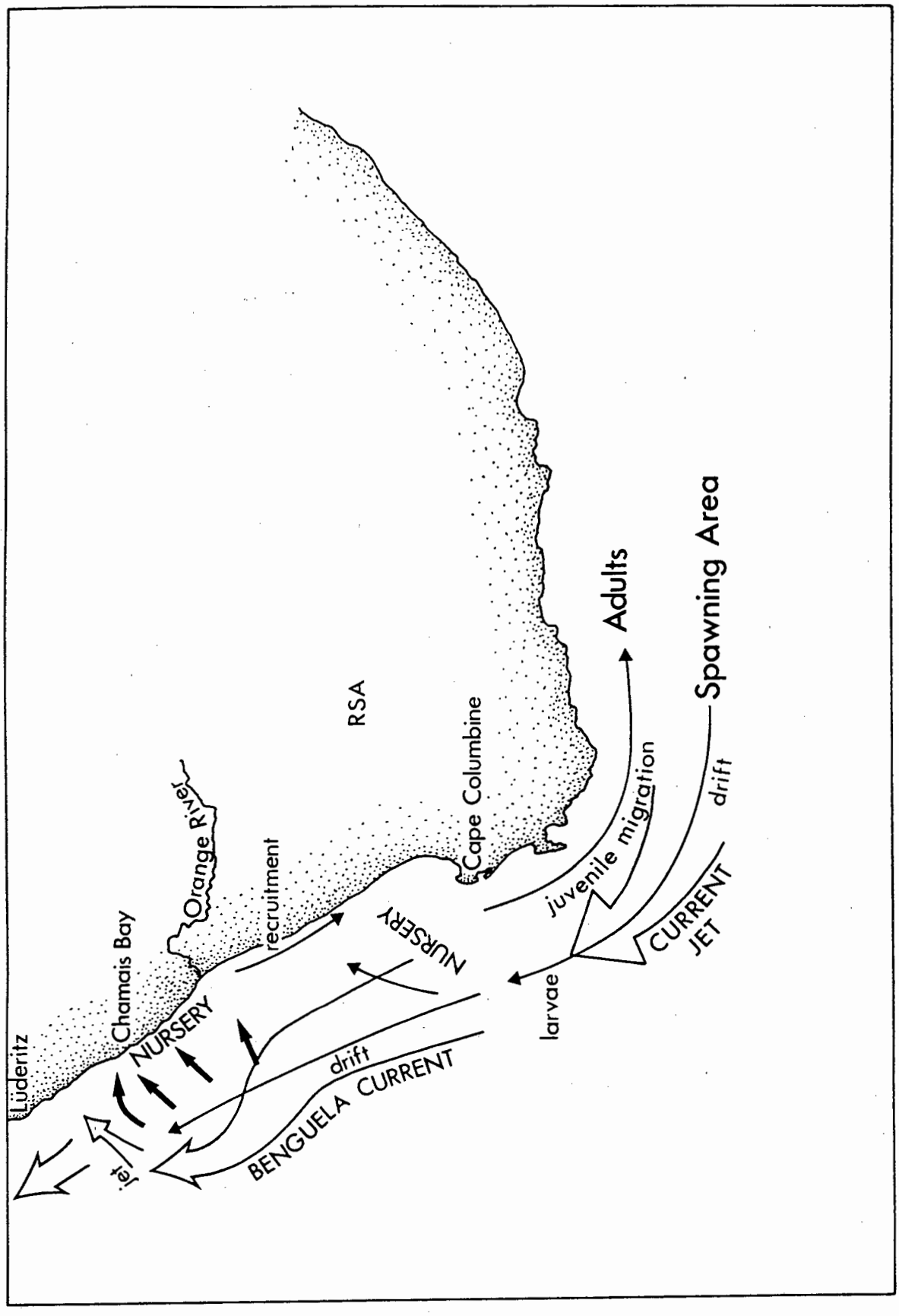


Figure 21 CONCEPT MODEL OF ANCHOVY MIGRATION IN THE SOUTHWESTERN CAPE RELATIVE TO SHOALS IN THE ORANGE RIVER REGION

References and discussion given in text.

of the stock such that they can be seen to conform to the expected pattern of migration (Harden-Jones 1965 & 1968) presented in Figure 1. The abundance of anchovy in the Orange River area may fluctuate according to the strength of the seasonal spawning off the Southern Cape, any variations in the Good Hope Jet and penetration of Agulhas Current intrusions into the Benguela System, the strength of the "barrier" effect off Lüderitz, or due to variable productivity in the Orange River region. But more specifically it may depend on an interaction between the advecting mechanisms and the poorly understood oceanography between the Orange River and Lüderitz. It would seem that the environmental barrier south of Lüderitz (Boyd and Cruickshank 1983; Shannon 1985; Shannon and Pillar 1986) may also result from strong oceanographic forces other than the temperature signal. It is therefore essential that a lot more attention be given to examining the oceanography in the region between Lüderitz and Hondeklip Bay. This is needed for a better understanding of the role and importance of the juvenile component of the South African stock found in this area and its relavance to the purse-seine fishery off the Cape.

B.3 DISTRIBUTION OFF NORTH AND CENTRAL NAMIBIA DERIVED FROM ACOUSTIC SURVEYS

Visser et al (1973) Hampton (1974) Cram and Hampton (1976) and Agenbag (1980) have plotted detailed outlines of fish shoals against plankton and hydrological distribution maps for Namibia in earlier years. In this study similar methods were applied but no attempt was made to obtain outlines of individual shoal groups. It was considered more appropriate to use generalised outlines of shoal distribution because (a) anchovy are highly mobile animals capable of covering 60 miles in a day (pers.obs.) and (b) anchovy distribution is very patchy (Murphy 1977, Fiedler 1978). Shoal groups tend to be concentrated in discrete pool areas. These pool areas or "basins" (termed "gross shoal regions" by Hampton et al 1979) can be related to environmental features such as temperature (Kruger and Cruickshank 1982; Boyd 1983; Boyd and Cruickshank 1983; Cruickshank 1983a, b & this study) and plankton distribution (Visser et al 1973; Kruger 1983; Cruickshank 1983a & this study). Thus if a shoal group was found to occur within a 20-mile grid square it was reasonable to accept the whole grid square as forming part of the fish distribution unless interrupted by a physical boundary.

In this section the yearly distribution of anchovy shoals determined during the acoustic surveys are illustrated on a monthly

basis in Figures 22 to 31. Comments on pertinent circumstances are given below in more detail for each year before the summary of these results is presented.

The most consistant areas of anchovy distribution were: (i) north of Palgrave Point (20°25'S) (ii) between Cape Cross (22°S) and Holloms Bird Island (24°40'S) and in the far south, (iii) between Chamais Bay and Port Nolloth (28°S to 29°20'S). There were also important centres of shoal distribution around Rocky Point (19°S) and south of Hollams Bird Island between Hottentot Bay and Lüderitz (26°S to 26°40'S). This is clearly seen in Table 1 which uses a relative index per degree of latitude for all the months in which distribution was mapped. Shoals were generally found in the upper 20m within 20 n.miles of the coast. South of Cape Cross, in particular, they were sometimes detected up to 50 n. miles offshore from November to February but even there shoals were always found within the 200 m isobath. In winter months anchovy shoals (particularly adults) occurred closer inshore than in summer.

TABLE 1. - FREQUENCY OF SHOAL DETECTION DURING 24 SURVEYS OFF NAMIBIA

Area	Latitude (°S)	Shoal Density index total	Shoal Density (%)	Frequency of Detection no. of cruises	Frequency of Detection (%)
rth of Rocky Point	18-19	33	12.2	21	87.5
cky Pt - Palgrave Pt.	19-20°30′	69	25.5	24	100.0
lgrave Pt - Cape Cross	20°30′-22	28	10.3	21	87.5
pe Cross - Walvis Bay	22-23	34	12.5	21	87.5
lvis Bay - Conception Bay	23-24	34	12.5	23	95.8
nception B. - Spencer Bay	24-25	27	10.0	19	79.2
encer Bay - Hottentot Bay	25-26	15	5.5	12	50.0
ttentot Bay - Lüderitz	26-27	8	3.0	8	33.3
deritz - Chamais Bay	27-28	1	0.4	2	8.3
amais Bay - Orange River	28-29	22	8.1	14	58.3

1978/1979

Figure 22 includes the distribution of pelagic fish shoals detected during a pilot survey off Namibia in October 1978. No catcher-vessel or other means of target identification was available. However, it is included here for its consistency with subsequent survey data. The first full-scale acoustic survey

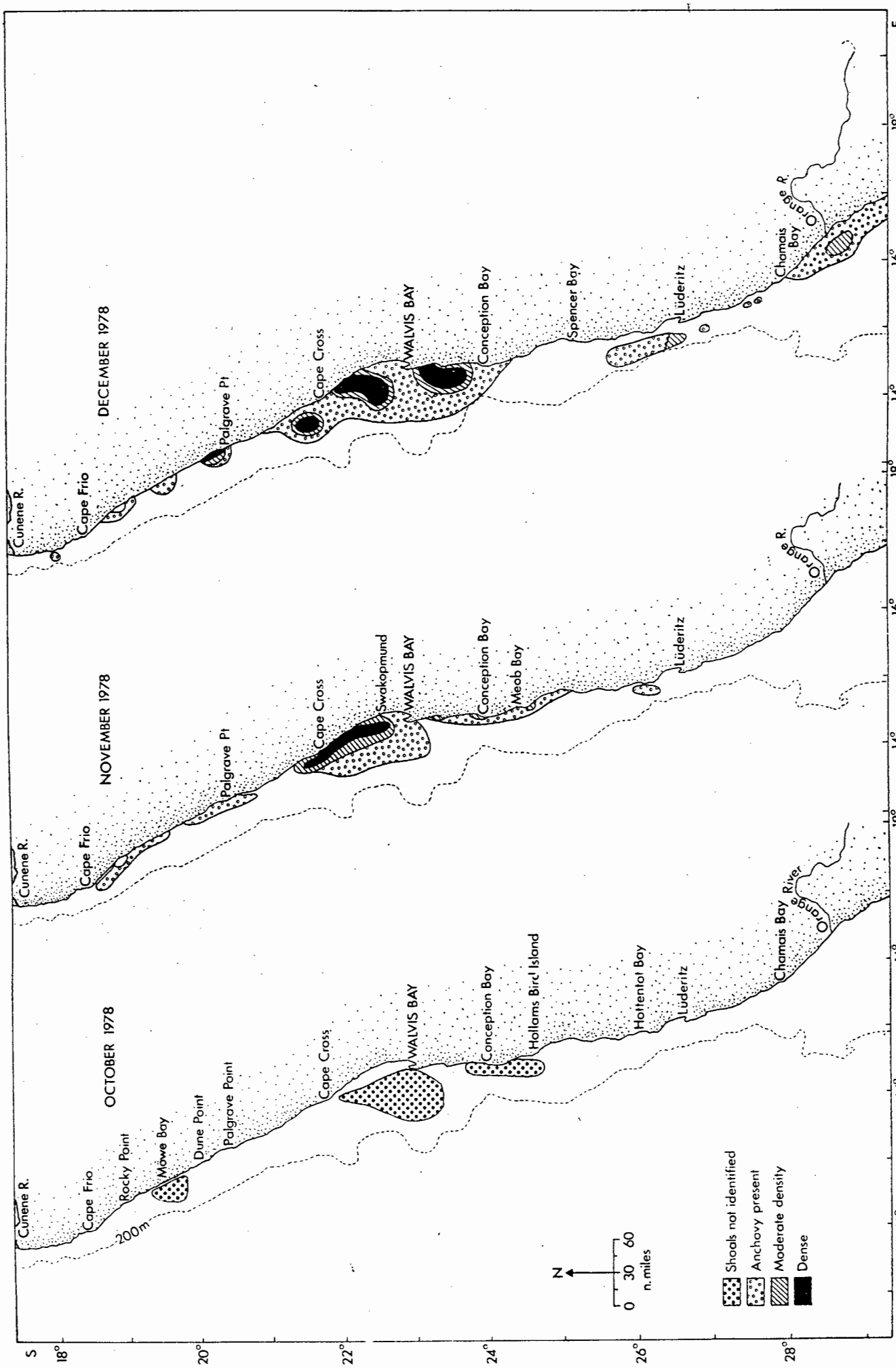


Figure 22 ANCHOVY DISTRIBUTION OFF NAMIBIA - SUMMER 1978

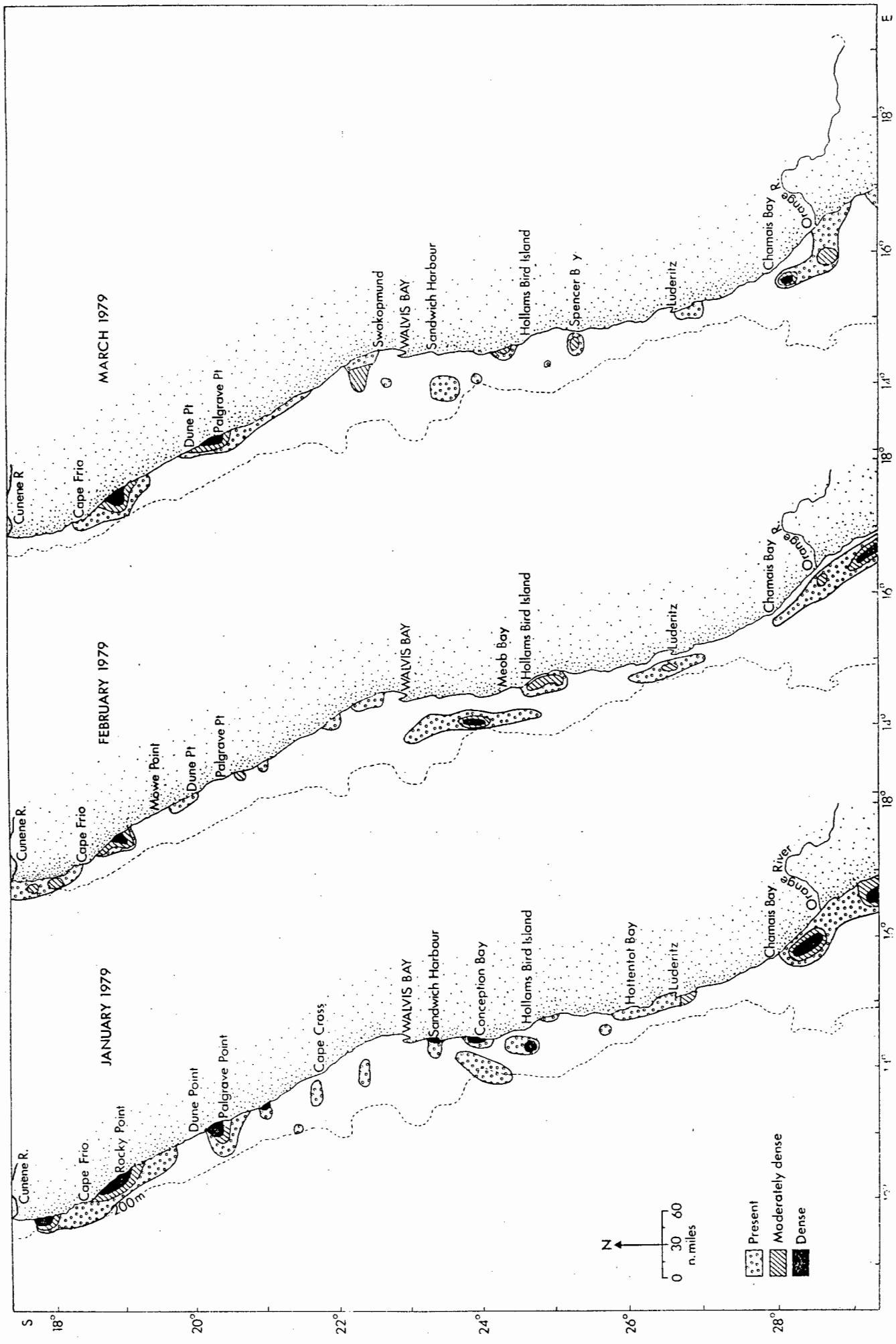


Figure 23 ANCHOVY DISTRIBUTION OFF NAMIBIA - SUMMER/AUTUMN 1979

on R.S. Benguela, with a catcher-vessel equipped for purse-seining in attendance, was conducted in November 1978 and repeated monthly until April 1979 (Figures 22-24).

From spring to mid-summer anchovy occurred between 21°S and 24°S but the main concentrations were from Cape Cross to Walvis Bay. Shoals of adults were widespread up to 20 miles offshore but extended as far as 45 miles offshore. From January there was a splintering of the adult shoal groups between Cape Cross and Walvis Bay with some shoals apparently having moved to the south of Hollams Bird Island and others northward beyond Palgrave Point. In February the main anchovy shoal groups occurred north of Rocky Point, in a continuous band 15-30 miles offshore between Walvis Bay and Hollams Bird Island, and within 15 miles from the shore from Hollams Bird Island south to Easter Cliffs (25°10'S). In autumn there was a shrinkage in shoal distribution with three main centres: off Henties Bay, Palgrave Point and Rocky Point, ending with the same distribution as that in November. Spawning also declines in March/April (King and O'Toole 1973; O'Toole 1977; LeClus and Melo 1983). The distribution pattern could thus, have been due to spawning migrations. But, it was also coincident with environmental factors such as water temperatures and plankton distribution suggesting that it could also have been influenced by feeding requirements.

Throughout the summer the distribution of shoals off the Orange

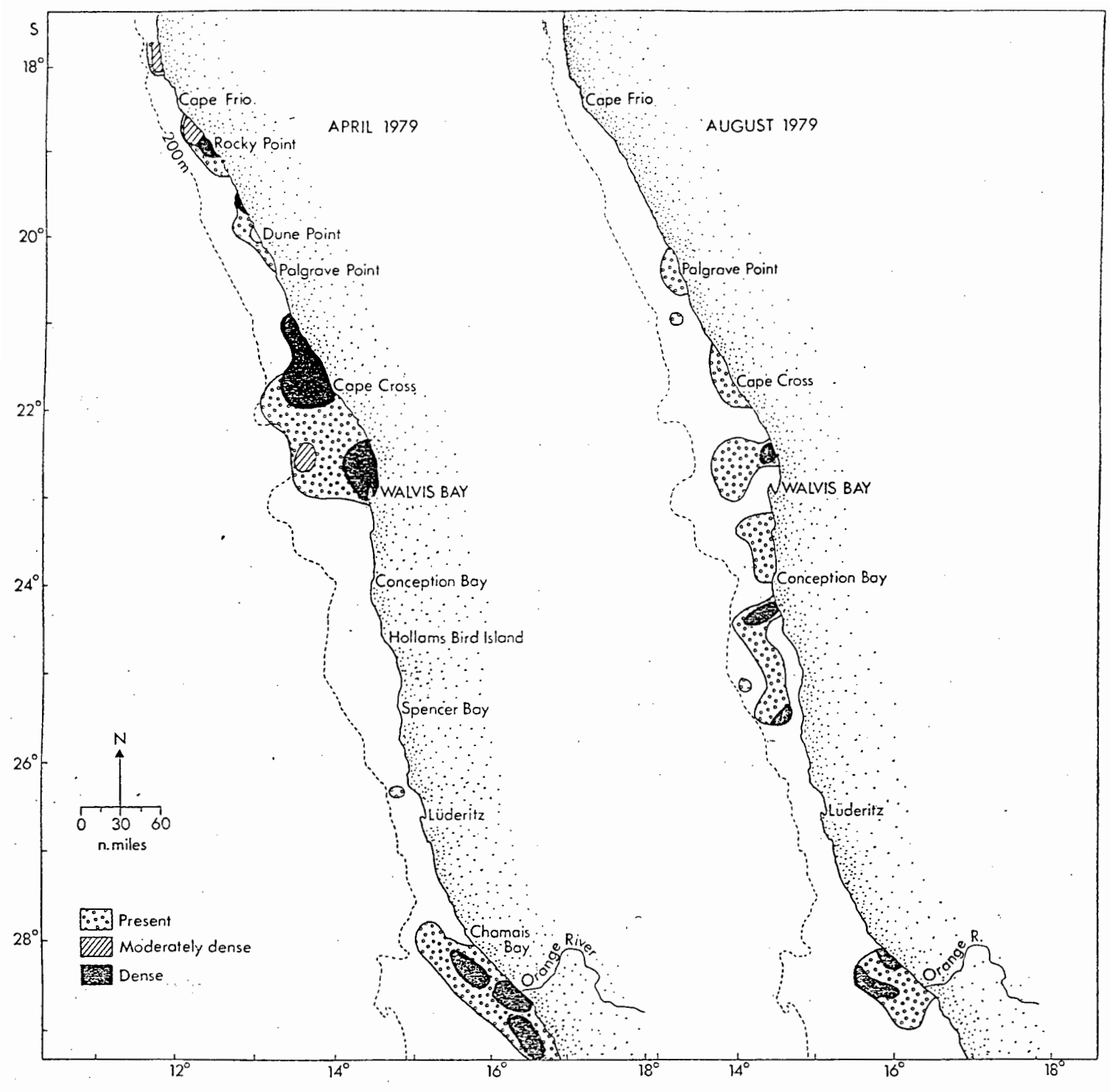


Figure 24 ANCHOVY DISTRIBUTION OFF NAMIBIA - WINTER 1979

River Mouth remained constant and was clearly unaffected by shoal patterns to the north of Lüderitz (See Chapter B.2). Anchovy egg distributions obtained from bongo net collections made in the upper 50 m during the same survey cruises (Le Clus 1979 & 1986) matched the fish distribution patterns. Commercial fishing operations in autumn concentrated on adult shoals in the north because only pre-recruit juveniles were caught at that time near to Walvis Bay (see B.4).

The August distribution pattern (Figure 24) represents the situation found during a survey conducted at the end of the commercial fishing season which, in 1979, concentrated on anchovy. The stock was obviously much depleted by the fishing operations. Shoals of recruits were widespread but at low density from just north of Cape Cross south to Spencer Bay and at Palgrave Point.

1979/1980

In summer 1979/80 (Figure 25), the fish south of Sandwich Harbour were primarily adults which probably constituted a spawning stock as their distribution matched the major distribution of the eggs collected by LeClus (1986). One of the catches near Sandwich Harbour comprised adults in "ripe and running" condition, *i.e.* with hydrated eggs, confirming that they were spawning shoals. Juveniles were only found in late summer and autumn (Figure 25). They occurred in the south from Henties Bay to near Lüderitz and some in the north off Sand Table Hill and north of Cape Frio. The northern anchovy groups were primarily adults.

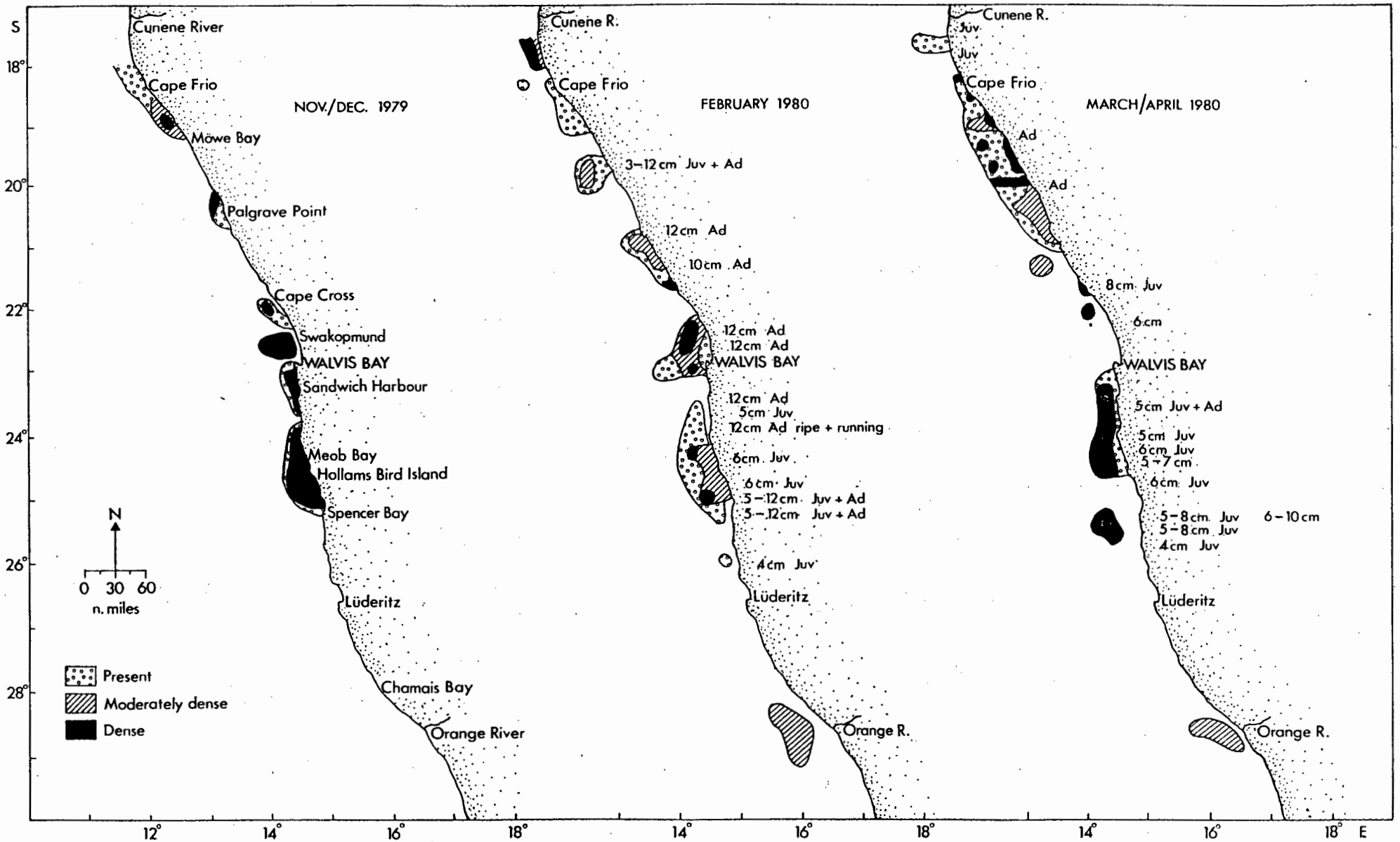


Figure 25 ANCHOVY DISTRIBUTION OFF NAMIBIA - SUMMER 1979/1980

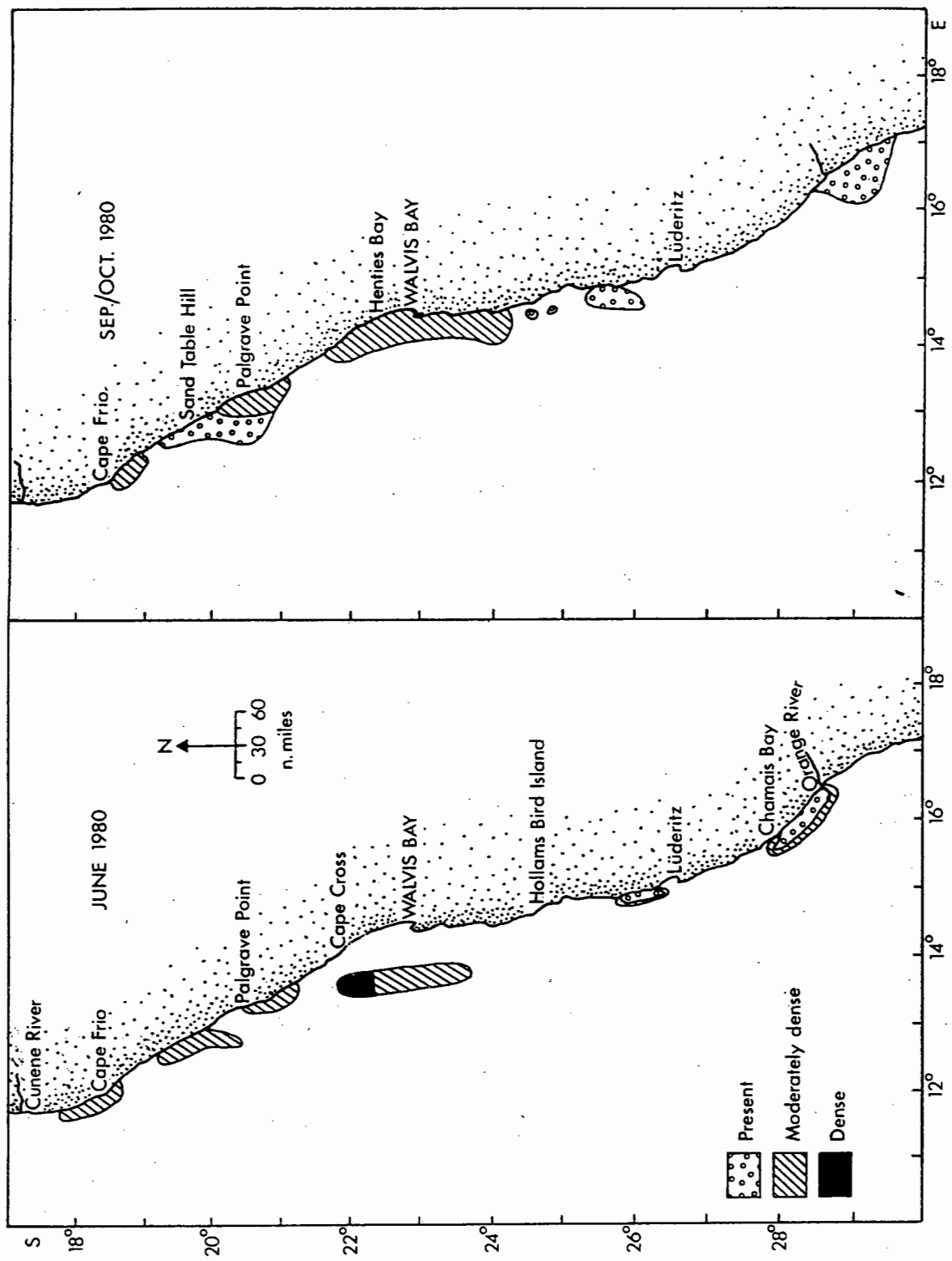


Figure 26 ANCHOVY DISTRIBUTION OFF NAMIBIA - WINTER 1980

Egg distribution extended 15-25 n.miles more offshore than the limits of the fish distribution, perhaps in part due to wind-driven drift as was suggested by O'Toole (1977). Nonetheless, the good corres- pondence between the distributions of adult and juvenile fish reported here and their eggs (described by LeClus 1986) strengthens confidence in the acoustically determined distribution maps.

1980/1981

In summer no spawning adults were found in the south (Figure 27). This corresponds with LeClus' (1986) findings that the major spawning concentrations shifted to the north from 1981 to 1983 with the colder water conditions intruding from the south (Mclain et al (1985). There was a large accumulation of recruit and pre-recruit shoals in autumn (March) between Walvis Bay and Sandwich Harbour (pers. obs. and Viljoen 1983). Interpretion of the pattern of monthly progression of increases in modal lengths, which are indicative of juvenile migration, is discussed in B.4. Shoals were again at low density in scattered patches over the whole range at the end of the commercial fishing season (Figure 28).

1981/1982

Figure 29 presents the anchovy distribution patterns found late in the summer of 1982. A marked difference in the distrib- ution pattern from previous years is seen in the generally low density of shoals south of Walvis Bay and the major distribution from Ambrose Bay to north of Cape Frio with densest aggragations

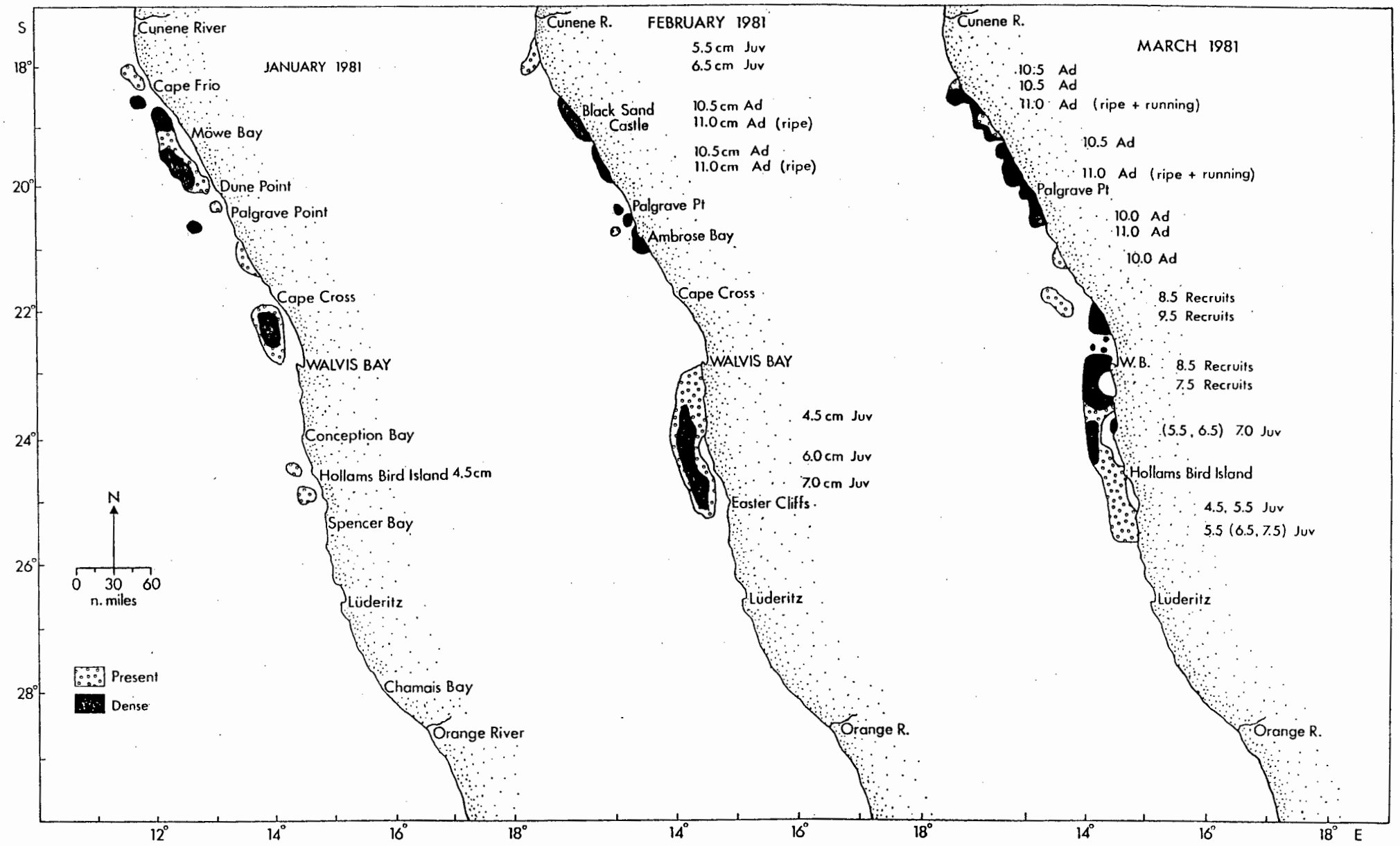


Figure 27 ANCHOVY DISTRIBUTION OFF NAMIBIA - SUMMER/AUTUMN 1981

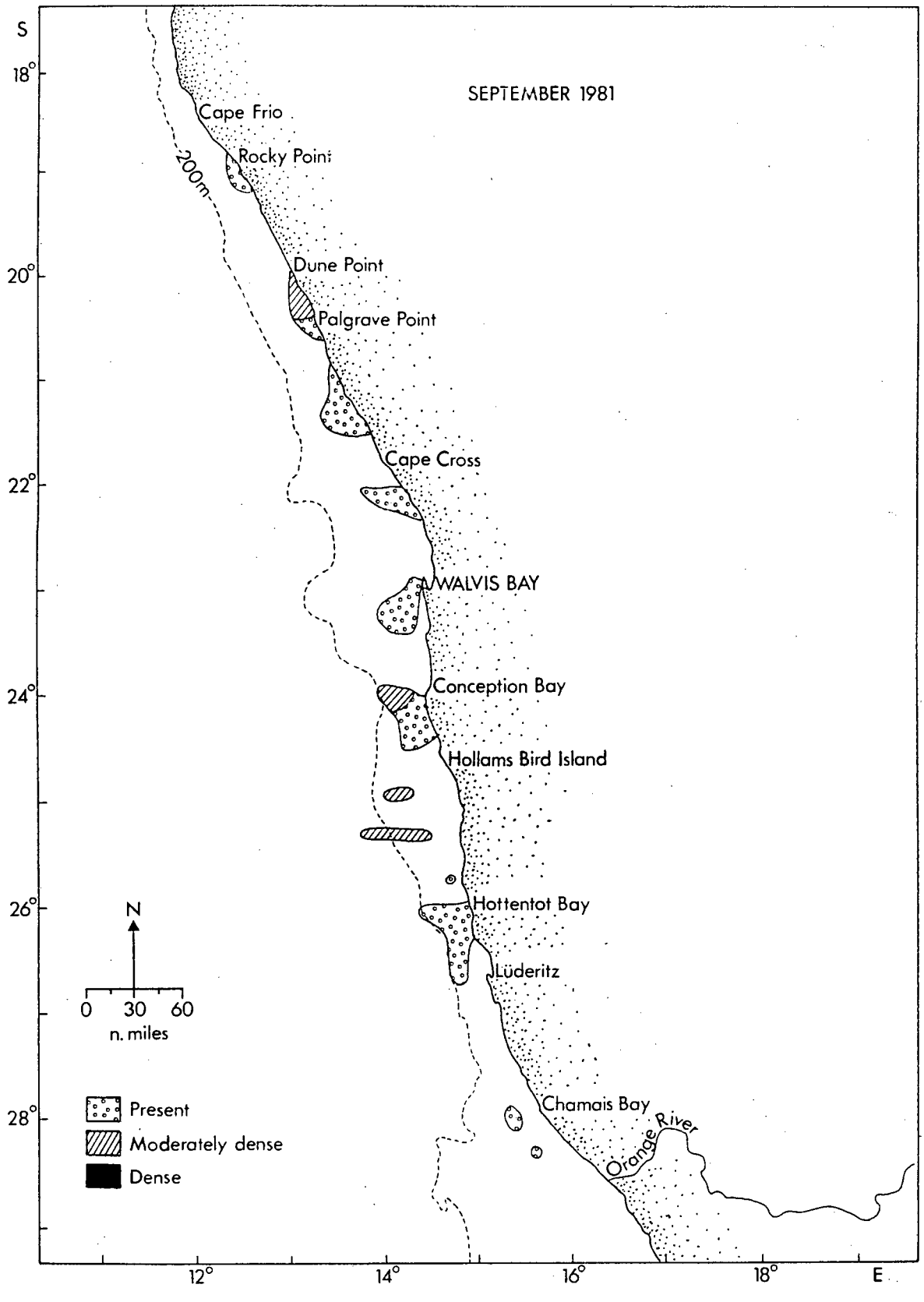


Figure 28 ANCHOVY DISTRIBUTION OFF NAMIBIA - WINTER 1981

between Palgrave and Rocky Points. This shrinkage in distribution towards the north was confirmed by the egg distribution and the winter catch distribution. It was associated with colder than average water temperatures (Boyd 1983; Cruickshank 1983a, Mclain et al 1985). Once again shoals of juveniles were consistently recorded in the far south around the Orange River.

In February and March 1982 it was possible to compare replicate transects of a large shoal group near Moewe Bay with roughly simultaneous cover from a spotter-aeroplane flying at 500 ft above sea level (Agenbag et al 1984). The results of the acoustic surveys, repeated for night and day, and the aerial survey done only at night were almost identical.

1982/1983

Financial restrictions precluded running monthly surveys with a catcher vessel and coverage of the whole coastal area. However, an intensive survey was conducted in April from just south of the Orange River 29°30'S to just north of Walvis Bay 22°30'S. Anchovy shoals were detected between the Orange River and Chamais Bay but none as far north as Walvis Bay (Figure 18). Details are discussed separately in Chapter B.2.

1984/1985

These surveys were carried out without a catcher vessel in attendance to the survey vessel R.S. Benguela. Nonetheless, the acoustic records of shoals were distinctive in the light of experience gained in previous surveys and of the egg distribution

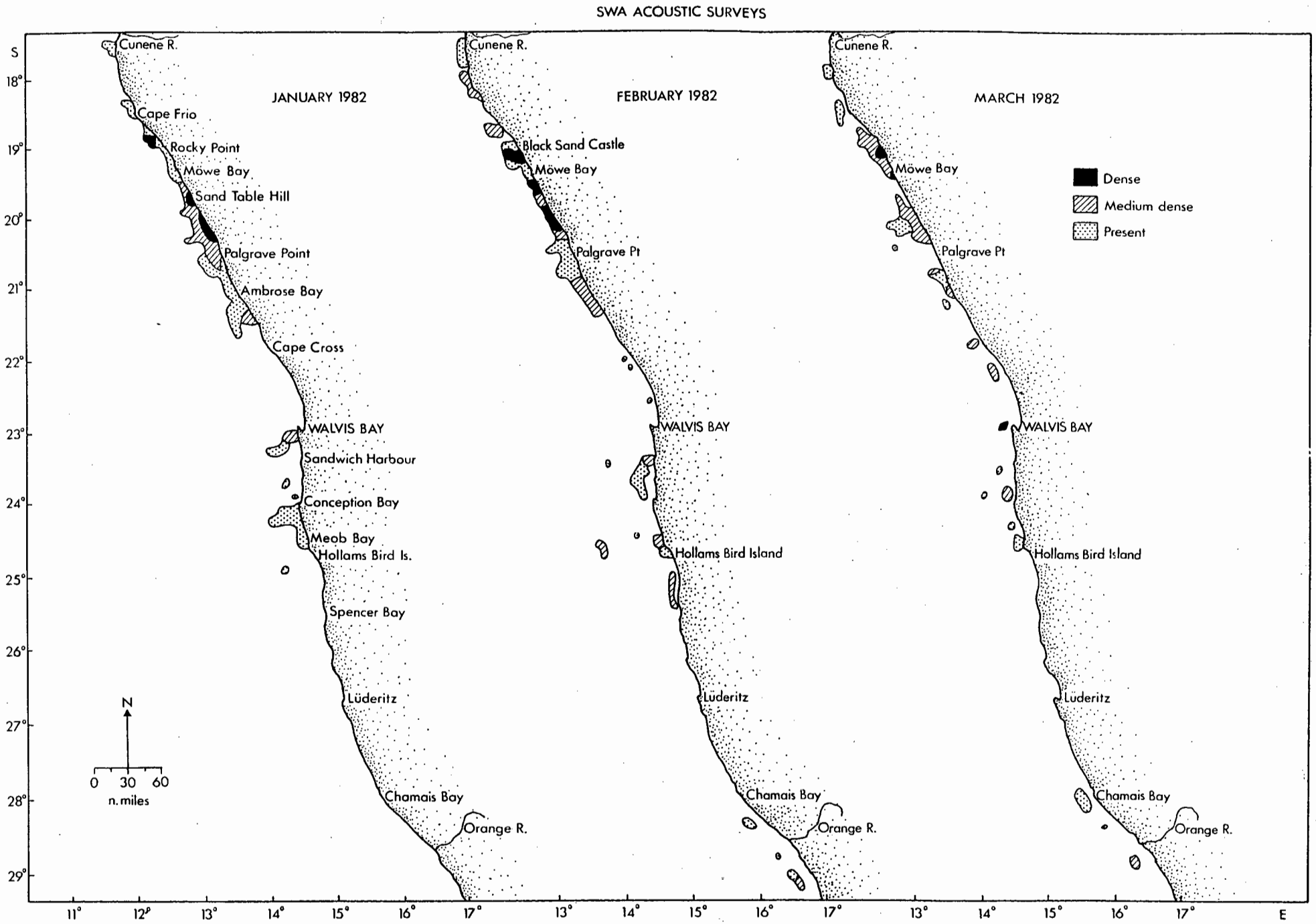


Figure 29 ANCHOVY DISTRIBUTION OFF NAMIBIA - SUMMER/AUTUMN 1982

described by Le Clus (1986). The general pattern of anchovy distribution (Figure 30) was similar to that recorded up until 1981 and LeClus (1986) described increased spawning in the Walvis Bay area after 1984. Thus, with the return of warmer water conditions (Mclain et al 1985) spawning shoals migrated further south again.

Shoals, which showed the characteristics associated with juveniles, formed a long band between 15 and 25 n.miles offshore in February from Spencer Bay to Ichaboe Island (26°20'S). The main distribution area at the end of summer was from Swakopmund to Palgrave Point.

The distribution of anchovy shoals recorded in June 1985 is presented in Figure 31. This survey did not extend beyond Rocky Point due to mechanical failure of essential equipment. Targets were identified by means of midwater trawls carried out by the survey vessel. The major distribution, comprising pre-recruit and recruit shoals, extended from Cape Cross to Spencer Bay in the south.

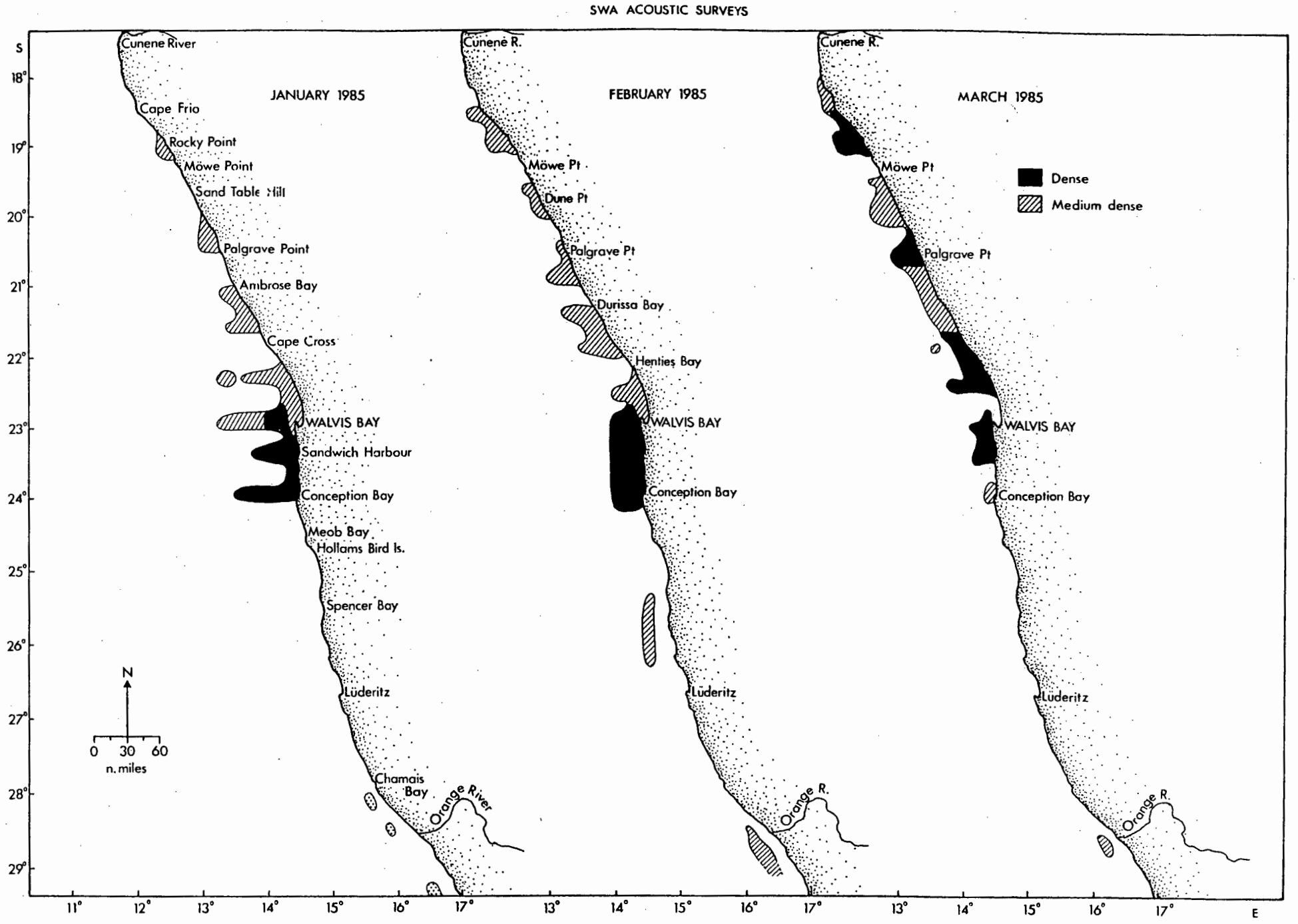


Figure 30 ANCHOVY DISTRIBUTION OF NAMIBIA - SUMMER/AUTUMN 1985

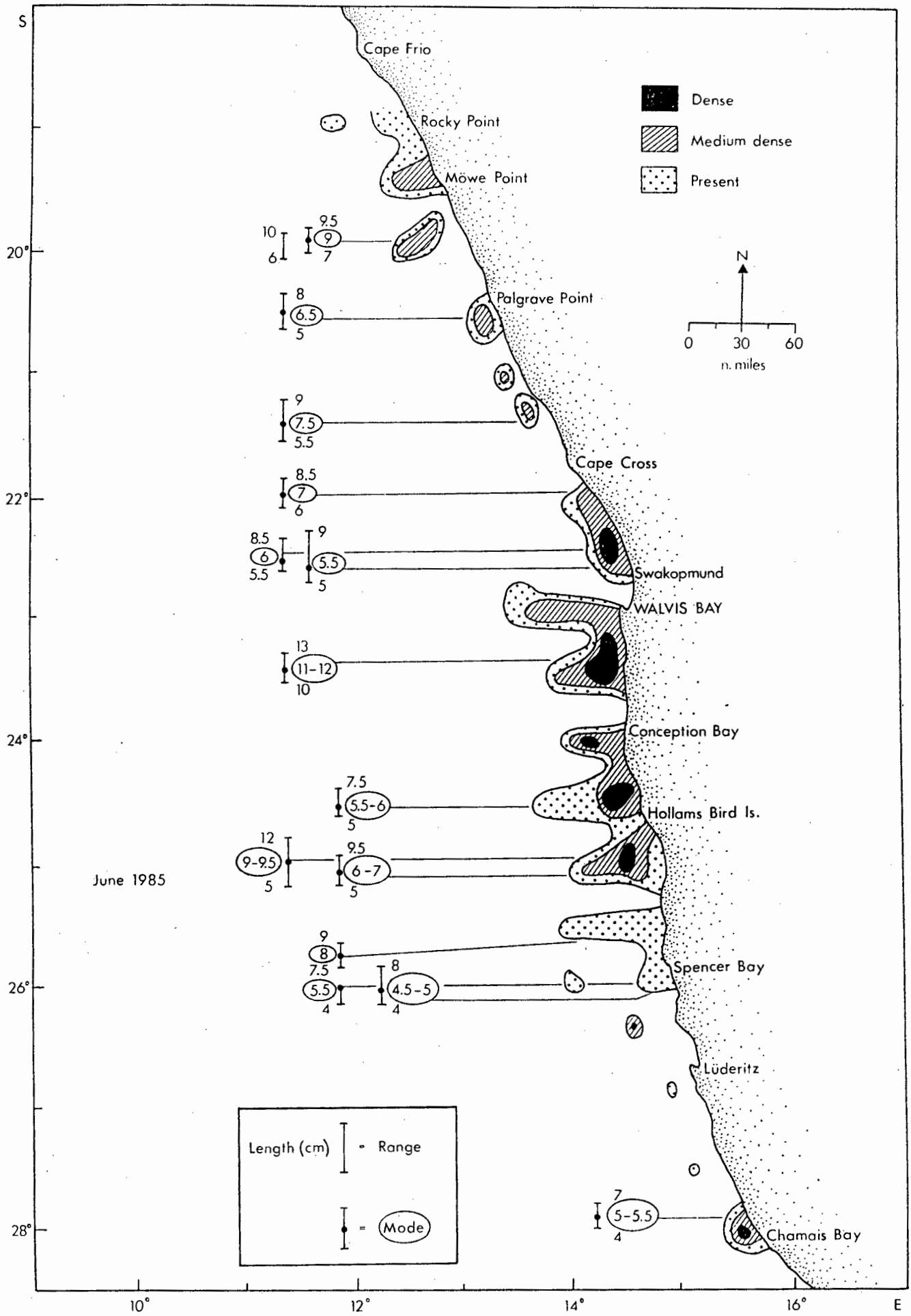


Figure 31 ANCHOVY DISTRIBUTION OFF NAMIBIA - WINTER 1985

SUMMARY

The distribution of anchovy each year showed a consistant pattern of aggregations generally close inshore in discrete areas or basins. These were:(i) between Cape Frio and Rocky Point, (ii) Moewe Bay to Palgrave Point (iii) Cape Cross to Hollams Bird Island, and (iv) Chamais Bay to Hondeklip Bay (Orange River area) as in Figures 22-31 and Table 1.

During peak spawning in mid- and late summer, shoals of ripe adults were found up to 25 miles offshore north of Palgrave Point and between Cape Cross and Spencer Bay, which are the major spawning grounds described by O'Toole (1978) and LeClus (1986). Hence these shoal groups were interpreted as forming the spawning stock. During winter, shoals north of Palgrave Point concentrated close inshore and were interpretted as feeding shoals since catch data indicated that their gonads were spent or inactive and many had full or partly full stomachs (see Section C). Adult shoals generally disappear from the vicinity of Walvis Bay in early winter and it is assumed that they move to the feeding grounds close inshore near Palgrave Point. This assumption is based on the fact that in winter commercial catches of adults are largely confined to the north of this point and that their presence there was confirmed by the present acoustic surveys. West of Spencer Bay small numbers of adult shoals were detected during some survey cruises, so there is a possibility of another adult

feeding ground in this area. Few shoals of juveniles were found north of Cape Cross. Pre-recruit and recruit shoals were mostly recorded between Cape Cross and Hollams Bird Island but also extended as far south as Lüderitz. The monthly shifts in distribution and size composition indicated that juvenile anchovy from the Walvis Bay area occur further south in summer and autumn but move northwards again from the Lüderitz area in autumn and early winter (detailed in B.4). It is assumed that this southerly distribution represents the nursery area. There is no clear pattern of southward movement from the major spawning grounds north of Palgrave Point. The prolonged occurrence of the juvenile shoals (March - August) in the Cape Cross to Sandwich Harbour area plus data on feeding frequency and distribution (Section C.), indicate that this is the primary winter feeding area for anchovy recruits. The relative distribution of the presumed summer feeding/spawning, nursery and winter feeding areas are set out in Figure 43, which is discussed in more detail later (Chapter B.5).

B.4 ANCHOVY LENGTHS RELATIVE TO DISTRIBUTION

Often length frequency distributions can show the appearance of young fish and can be used to monitor the influx of recruits. In this study, fish of 10.0-13.5cm length (Lc) are considered adults, 7.0-10.0cm as recruits and 3.5-7.0cm as pre-recruits. Data reported here are summarised from unpublished Sea Fisheries records of commercial fishery landings at Walvis Bay. The length ranges obtained from target catches during the summer acoustic surveys as well as those from the midwater trawl catches of a survey in June 1985 are listed in Table 2. Modal lengths are recorded alongside shoal distribution in Figures 26, 28 and 32. There is a general concentration of adults to the north of Palgrave Point (20°-21°S) and recruits to the south. Pre-recruit juveniles were detected south of Walvis Bay (23°S) suggesting a southern nursery ground.

a) SURVEY DATA

Table 2 shows clearly that from 1980 to 1982 there was a grouping of adults north of 21°S in January. This group spread southward in February 1980 then returned (or contracted) to north of 20°S in March. In 1982 this group remained between 19°S and 20°S in late summer although another small group occurred around Lüderitz (26°40'S) in February. Another, or possibly the same, group was detected off Walvis Bay (23°S) in March.

Corresponding to the far northern spawning areas there were a few post-larvae and pre-recruits in 1980 and 1981 around Rocky Point (19°S) and Cape Frio (18°S). These apparently remained north of Cape Frio and their low numbers indicate that they may have had little effect on the annual "run" of recruits off Walvis Bay (23°S).

The major grouping of juveniles was to the south of Walvis Bay. They were absent or few in numbers in January but were widespread between Walvis Bay (23°S) and Lüderitz (26°40'S) in February and March, notably in 1980. The table shows only the size ranges. The modal lengths presented with the monthly distributions in Figures 26, 28 and 32 indicate a predominance of pre-recruits (5.0-7.0cm). The juvenile group expanded northward as far as Palgrave Point (21°S) in March 1980. Within this large range of latitude covered by juvenile fish in late summer and autumn there is a mixture of size ranges but there is a discernable south to north trend with small fish (3.0-5.0cm) between Lüderitz and Spencer Bay (25°S), larger juveniles (5.0-7.0cm) around Walvis Bay and recruit fish (7.0-10.0cm) from Walvis Bay to Palgrave Point. The mixed distribution of pre-recruit sizes would be in keeping with a passive influx from the northern and central spawning areas dependant on a variable southward flow of water due to the fluctuating strengths of factors such as eddies associated with upwelling tongues, southward penetration of the Angolan Current, or other sources of southward flow as described in Chapter B.1.

This is most clearly seen in 1981 when the surveys were able to closely monitor the progression of juvenile shoals from January to March both acoustically and by purse-seine catches with follow up data derived from commercial catches. The distribution and related modal lengths of fish sampled are presented in Figure 28 in addition to the length ranges given in Table 2. The overall distribution and an interpretation of the movements of pre-recruits for that year are given in Figure 41. Three clear sub-groups of adults north of Cape Cross can also be distinguished. This pattern is consistent in all the years of this study:

In January 1981 two restricted groups of young fish were detected around Hollams Bird Island. In February a broad band of juvenile fish in a dense, near-surface layer extended between 10 and 30 miles offshore from Walvis Bay to near Spencer Bay. Sampling showed that this layer consisted of young fish (4.5cm) at Conception Bay and late stage pre-recruits (7.0cm) off Easter Cliffs in the south. In March this band extended even further south to Ichaboe Island. The same size progression was still evident in the south but most of the smaller fish (4.5-5.5cm) occurred around Spencer Bay while there was an increase in modal length from these pre-recruits to recruits of modal length from 7.0 to 9.5cm from Conception Bay to Cape Cross further north. Furthermore, there was a matching northward shift in density of these juvenile shoals (January to March) from south of Conception Bay to between Conception Bay and Cape Cross, with the greatest accumulation off

Walvis Bay. Many shoals of 6.0-7.5 cm pre-recruits were observed moving distinctly northward from Sandwich Harbour to Walvis Bay where they accumulated in masses which were visible at the surface by day and night. Commercial fishing operations from April onward confirmed the presence of these recruits around Walvis Bay in April and May. In consequence the major concentration of effort was made on the adult fish in the north between Moewe Bay and Palgrave Point. From July to August the fishing concentrated on the recruit fish between Cape Cross and Hollams Bird Island.

The 1982 summer length frequencies do fit the general grouping of adults to the north and juveniles to the south (Table 2). However, from 1980 to 1982 the northern group of adults was increasingly made up of younger (smaller) fish. This may indicate a decline due to overfishing but is more likely (LeClus pers.comm.) to reflect spawning maturity at an earlier size, dependant on the suitability of prevailing conditions. The juvenile grouping in the south is confined to the Lüderitz/Spencer Bay area (27°-25°S) and shows a northward increase in size. But, in 1982 these were large pre-recruits and recruit-size fish (6.5-8.5cm) with no younger fish except a few off Ichaboe Island (26°S) in March. The northern grouping also shows a spread of early recruits present in March, further north than usual. The winter commercial season was based on adults in the north in autumn followed by a minor influx of recruits from the south in June and an overall recruitment

failure. This has been ascribed to a northward shift in spawning concentrations and recruitment failure due to colder than average water temperatures intruding from the south (Boyd 1983; Cruickshank 1983; Mclain et al 1985; LeClus 1986).

An acoustic and trawling survey conducted in midwinter 1985 (Table 2 & Figure 31) also showed a distinct south to north progression of increase in modal length from 4.5 - 5.5cm in the Spencer Bay area (25°S) through 5.5-6.0cm north of Hollams Bird Island (24°S) and 5.5 to 7.0cm off Henties Bay and Cape Cross (22°S). Recruit fish also show a trend of increase from Spencer Bay to Hollams Bird Island and from 7.0cm off Cape Cross to 9.0cm off Dune Point. It is uncertain whether the small group of recruits (mode 6.5cm) at Palgrave Point originated from the north or from the Walvis Bay area.

The pattern strongly suggests that there is a passive advection of post-larval fish from the major spawning area around Walvis Bay southwards towards a nursery area reaching as far as Lüderitz during summer with an active return migration of pre-recruit and recruit juveniles northward to the Walvis Bay area in autumn and winter (e.g. as in Figure 41).

b) Winter Commercial Landings

Figures 32a-38 illustrate the longshore distribution of anchovy catches annually from 1979 to 1985. They also indicate whether

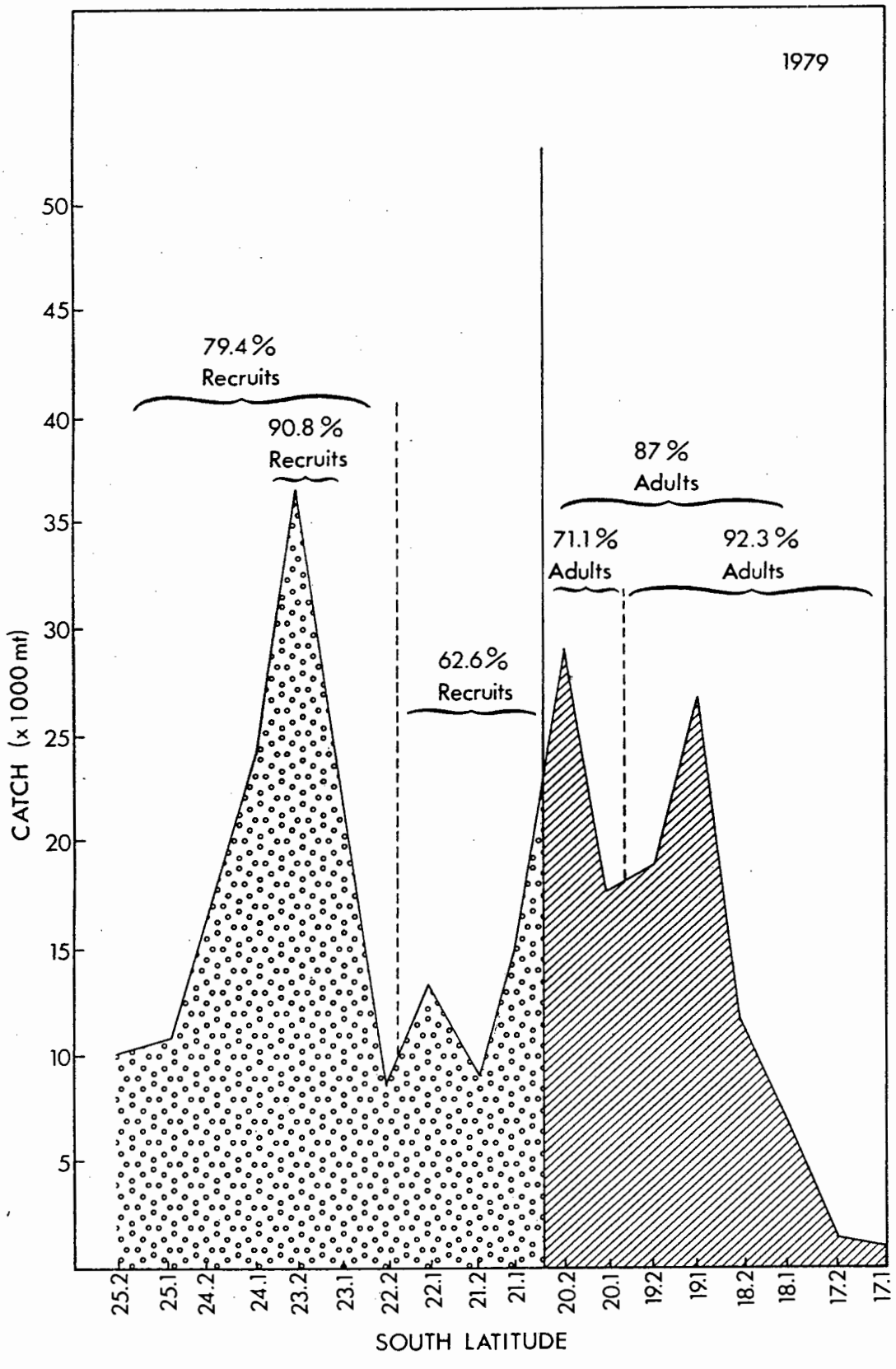


Figure 32a COMMERCIAL CATCH TOTALS cf. LATITUDE OFF NAMIBIA, 1979

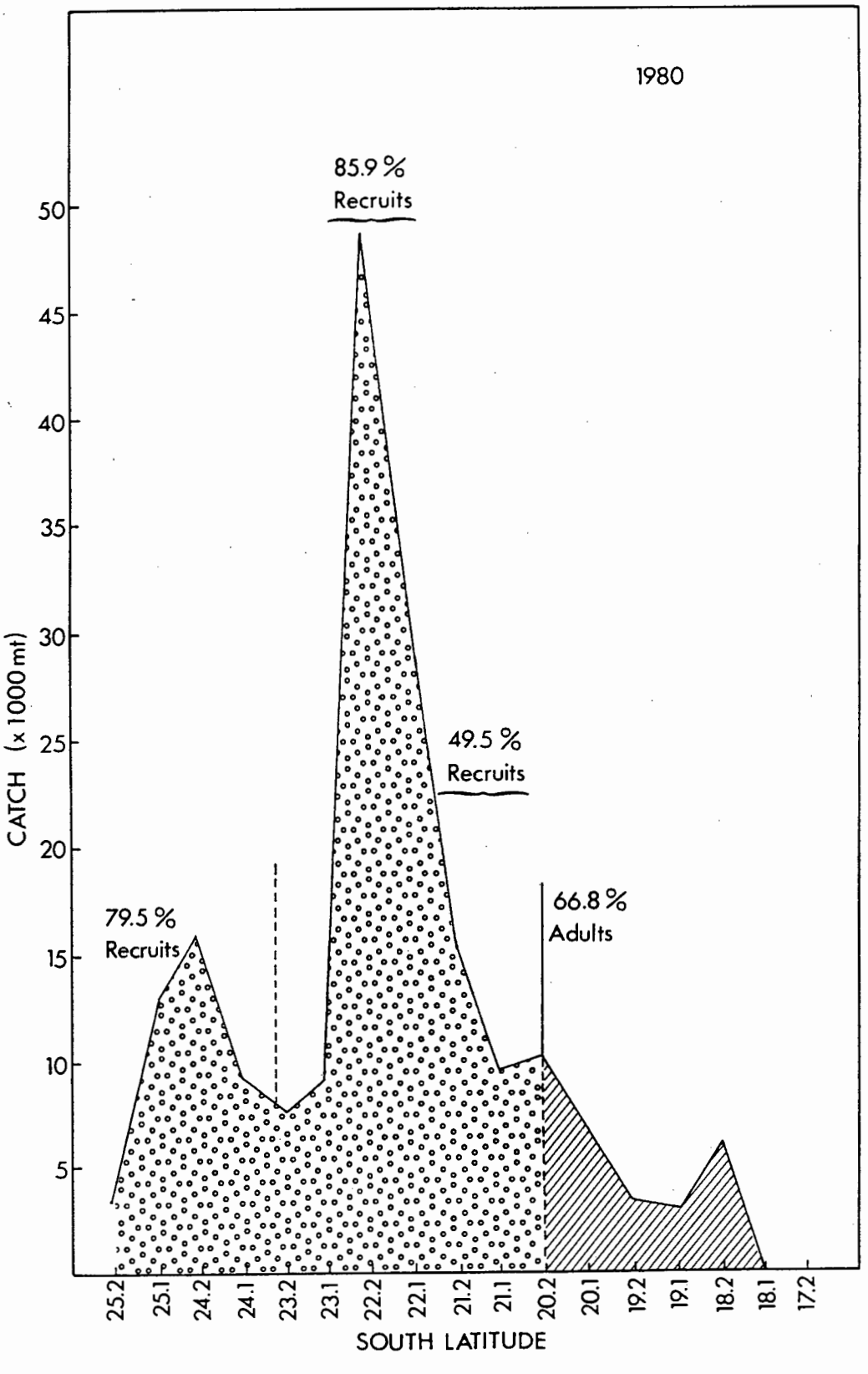


Figure 32 COMMERCIAL CATCH TOTALS cf. LATITUDE OFF NAMIBIA, 1980

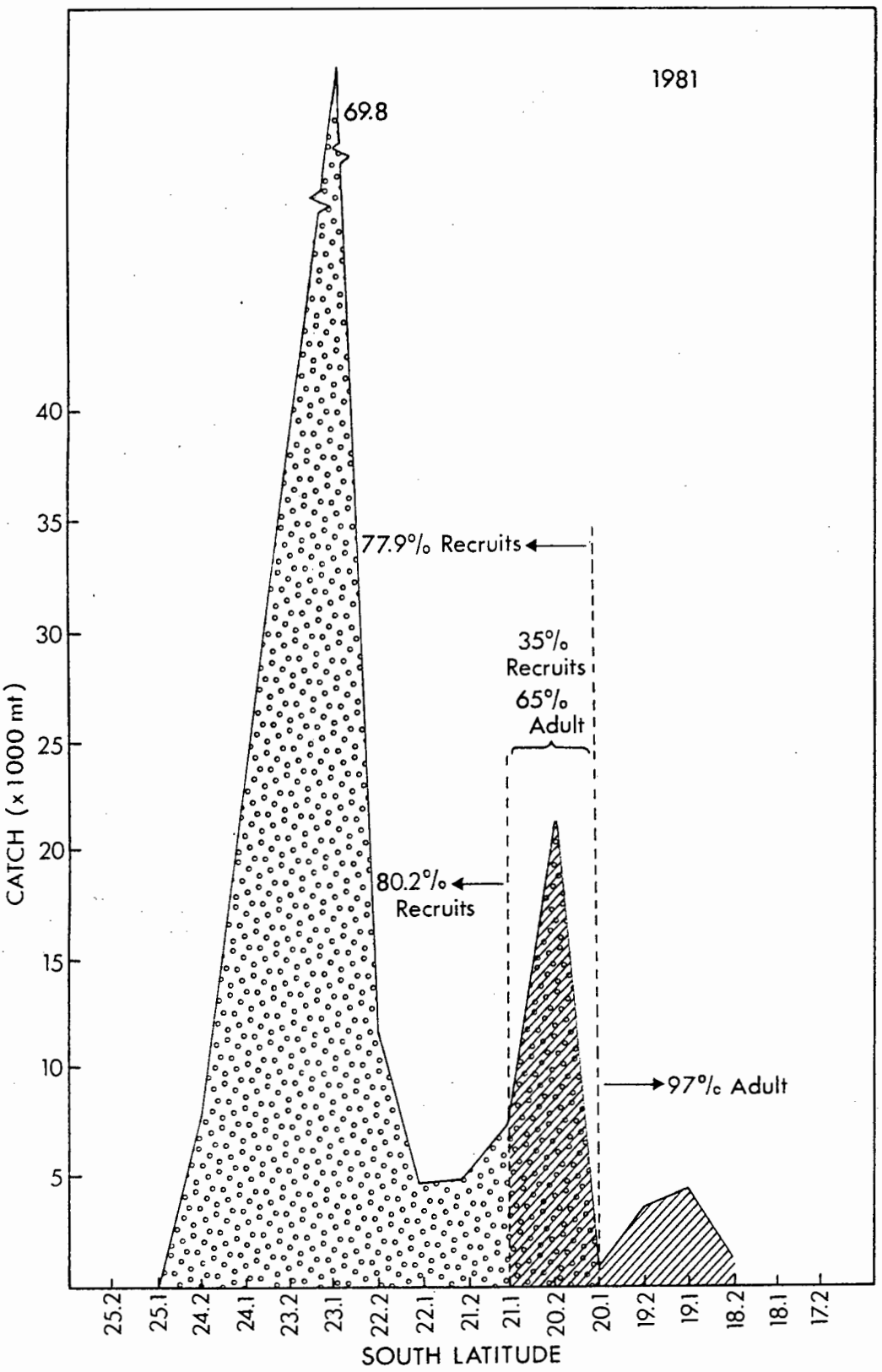


Figure 33 COMMERCIAL CATCH TOTALS *cf.* LATITUDE, 1981

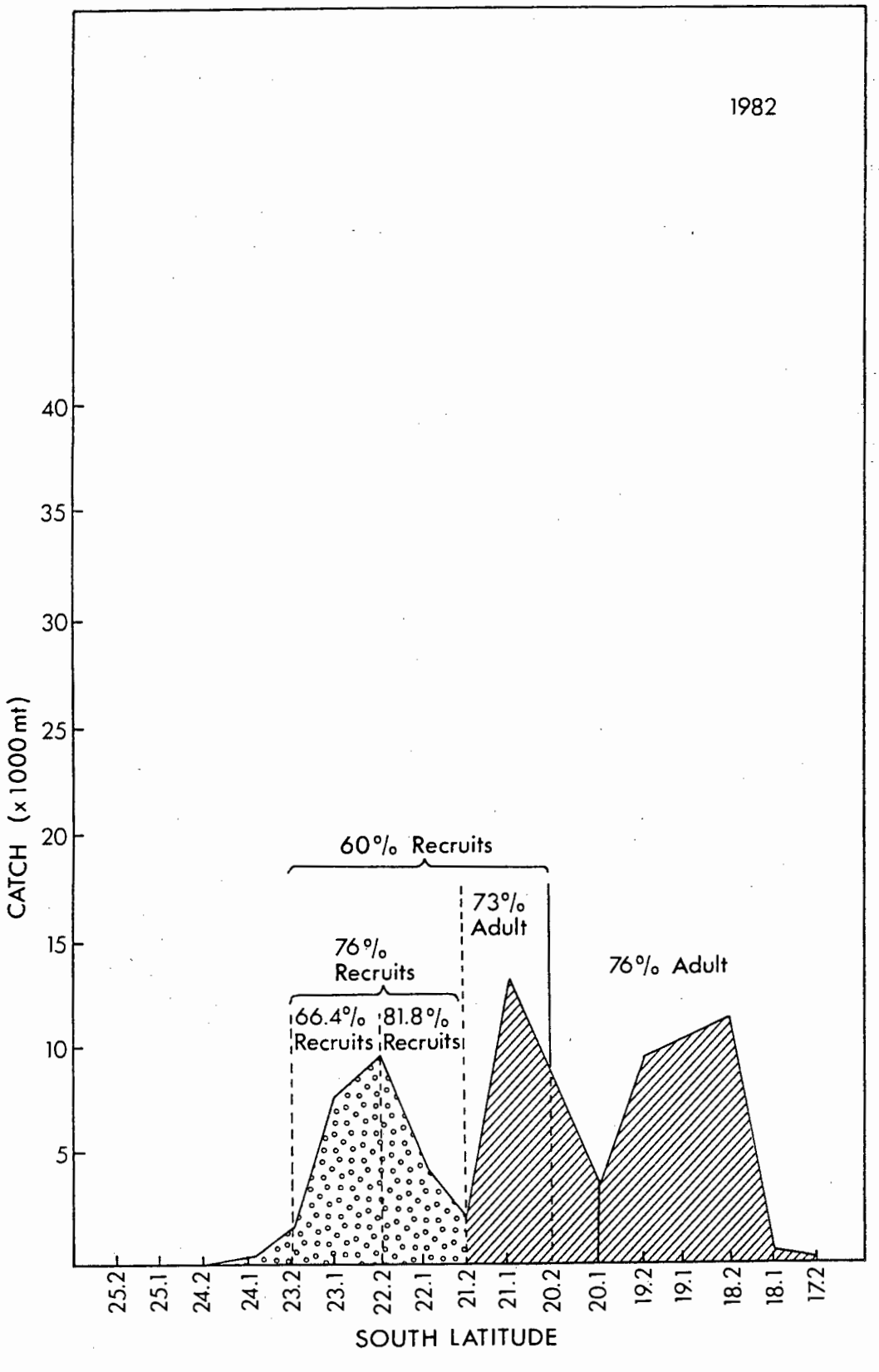


Figure 34 COMMERCIAL CATCH TOTALS cf. LATITUDE, 1982

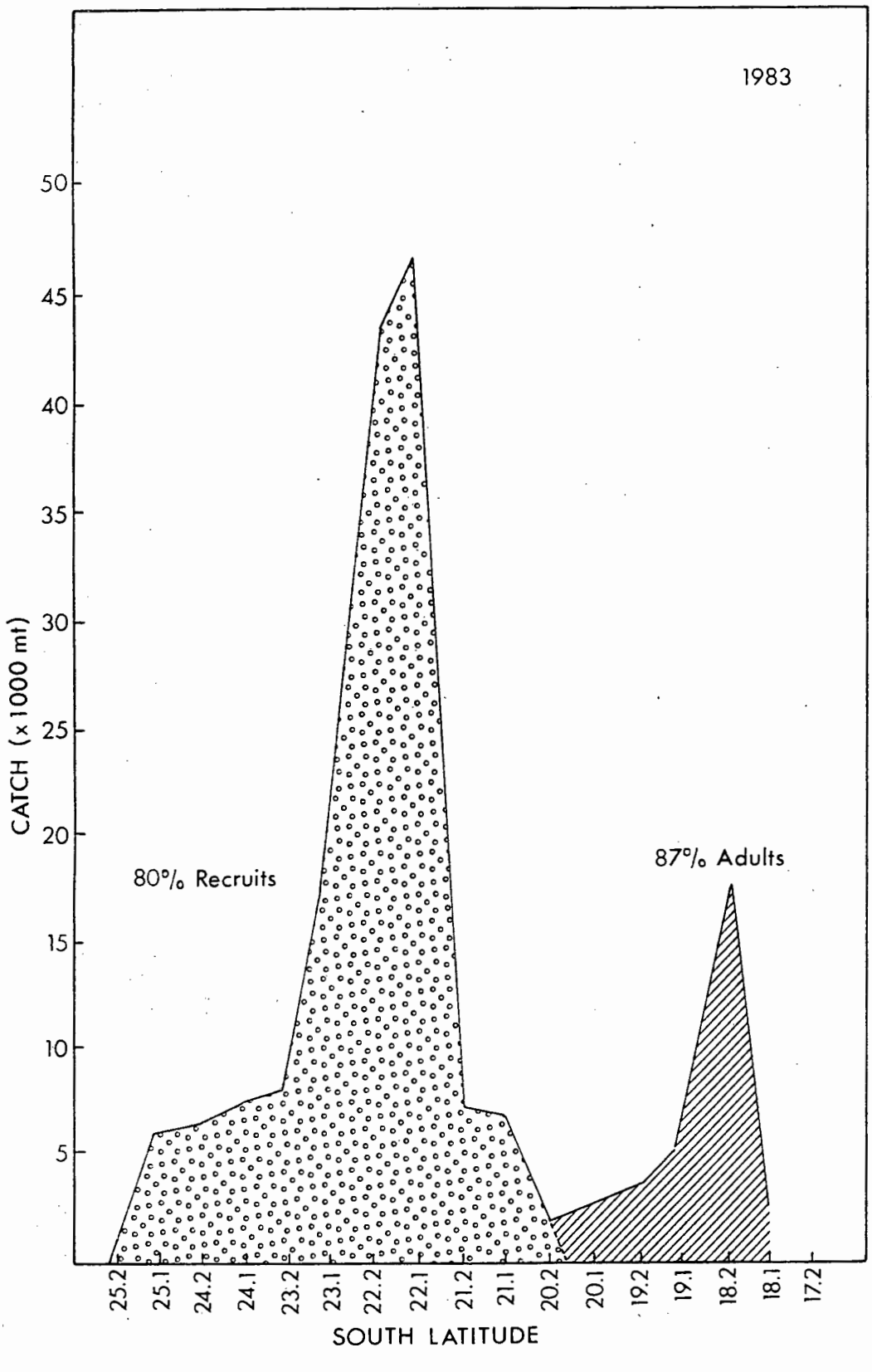


Figure 35 COMMERCIAL CATCH TOTALS cf. LATITUDE, 1983

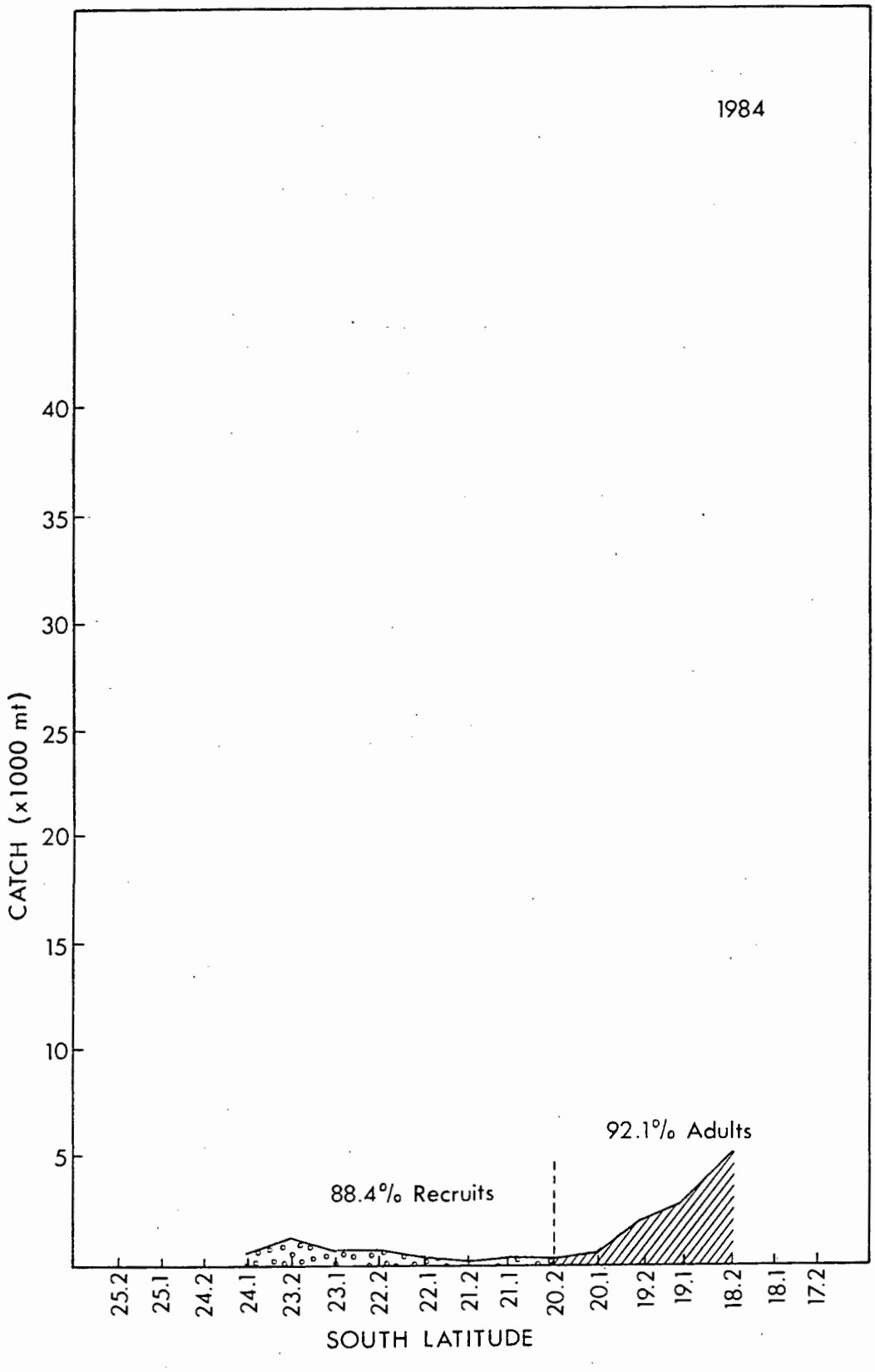


Figure 36 COMMERCIAL CATCH TOTALS cf. LATITUDE, 1984

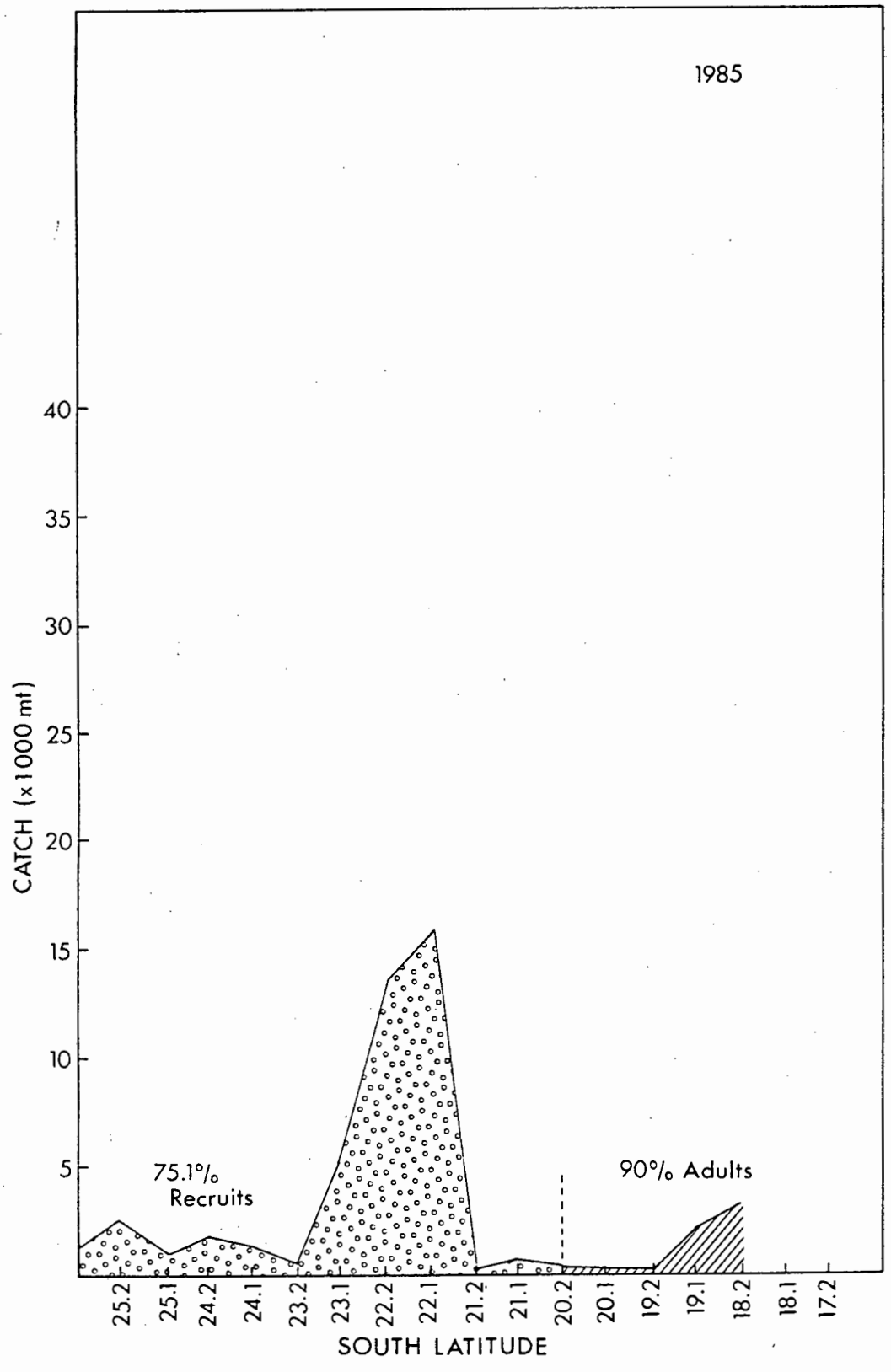


Figure 37 COMMERCIAL CATCH TOTALS cf. LATITUDE, 1985

adults or recruits made up the dominant portion (60-90%) of the catches. Throughout this period there was a clear tendency for the northerly catches to be based on adults while recruits made up the predominant catch in the south. Figures 38 and 39 map the distribution of fishing activity in two fairly typical years. The offshore depth distribution and catch totals per degree of latitude are also indicated in Figure 39 and the average offshore catch totals north and south of 22°S are presented in Figure 40. The overwhelming predominence of recruit catches more offshore, mainly between 22°S and 24°S, compared to the distinctly inshore distribution of adults in the north are obvious.

Comparing the catch distribution for each year (Figures 32-37) 1980 and 1981 are essentially similar except that more fish (65% adults) were caught around Palgrave Point (21°S). Figure 34 clearly shows the recruitment failure in 1982 due to cooler than average conditions (Boyd 1983; Cruickshank 1983a; Mclain et al 1985). As a result, the catches of adult fish in the north, though average, formed about two thirds of the season totals. Recovery is reflected in the 1983 (Figure 35) data with season totals similar to 1980 and 1981. The overall range of catches is roughly the same in all years but, after 1981 there is a discernable northward shift particularly in regard to adults. In 1980 and 1981 most adults were caught around 20°S. This broadened out between 21°S and 18°30'S in 1982 and in 1983 the peak of adult catches was distinctly north of Rocky Point at 18°30'S. The peak of recruit catches

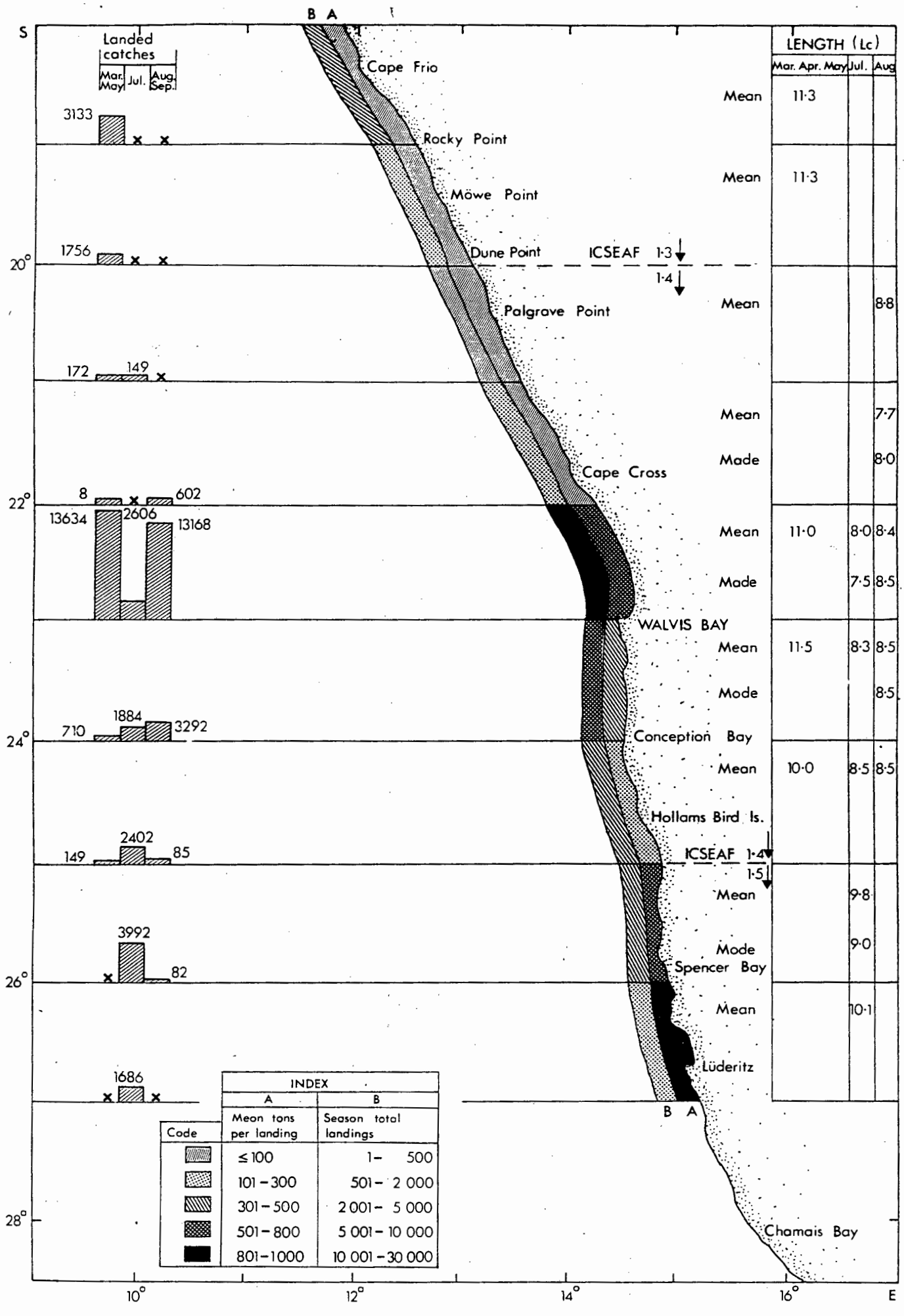


Figure 38 WINTER CATCH DISTRIBUTION AND MODAL LENGTH PER MONTH AND HALF DEGREE OF LATITUDE, 1985

shifted only marginally north from between 22°30'S and 23°30'S to 22°S in 1983 and 1985. All signs of any pattern were obliterated in the disasterous 1984 season totals (Figure 36) but 1985 showed a re-emergence of the earlier pattern still slightly more north than usual (Figure 37).

The northward shift in fish distribution corresponds with the intrusion of cooler than average conditions advancing from the south from 1981 to 1983 (Mclain et al 1985) which was pushed back by the El Niño-type conditions in 1984 (Boyd and Thomas 1984). LeClus (1986) described a similar reduction in the spawning areas between Cape Cross and Hollams Bird Island and emphasis on spawning in the north from 1981 to 1983 and return towards the south after 1984. If recruitment originated from a northern nursery area, the cooler conditions in the south would be expected to have disrupted the pattern by confining the recruit shoals further north but might not have caused as marked a reduction in recruitment. That the basic pattern remained, but with a northward shift in peak catches, suggests that although spawning shifted markedly north, the southward transport to a southern nursery and northward recruitment of juveniles in winter continued. Declining catches could then have reflected reduced survival of post-larvae in the cooler conditions. If anchovy continue to recruit from a nursery area south of Walvis Bay, one would expect that they would still have been vulnerable to the fishery in the region of Walvis Bay. This is reflected in the figures where adults in the

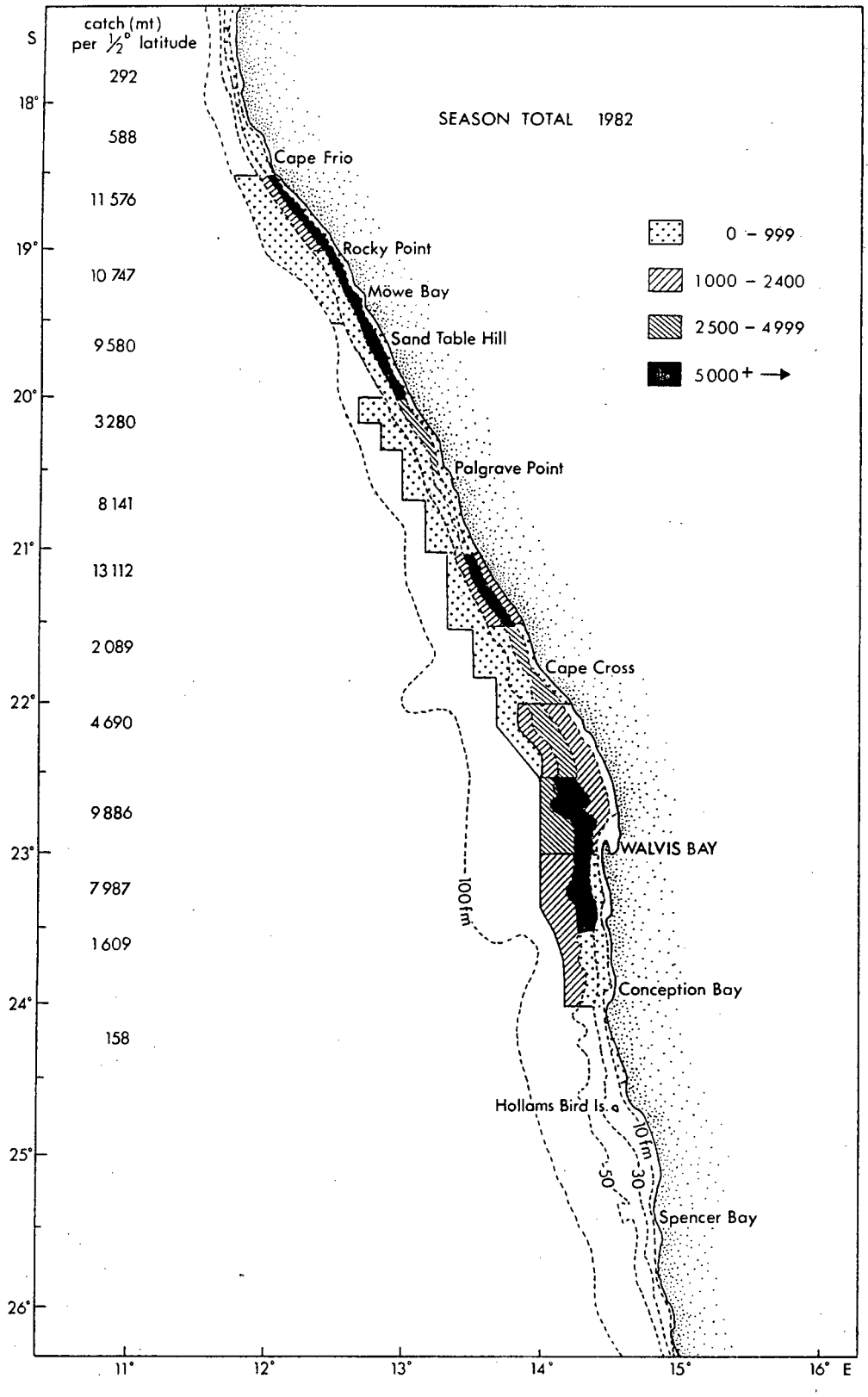


Figure 39 CATCH TOTALS cf. DEPTH & HALF DEGREE OF LATITUDE, 1982

north show a more marked shift due to the changing environment.

The annual patterns of fishing activity derived from catch statistics (Sea Fisheries unpublished data) were as follows:

1980:

Adult anchovy in the north dominated the early season catches. Then fishing shifted south to between Cape Cross and Walvis Bay as recruit fish became available in this region. Later, with a large influx of recruits in the south, catches extended to between Hollams Bird Island and Spencer Bay but the overall peak of activity remained around Walvis Bay where the highest totals were recorded for the season.

1981:

April catches were made up of adults in the far north around Rocky Point and Moewe Bay (19°-19°30'S). In May the catches shifted south of Palgrave Point (21°S) with an influx of juvenile fish around Walvis Bay (23°S). The peak of fishing shifted still further south with large quantities of recruit fish caught in deep waters (>50 fms) between Cape Cross and Walvis Bay (22°-23°S) In July the anchovy fishery was dominated by recruits caught between Walvis Bay and Hollams Bird Island (23°-24°S).

1982:

Catches of adult anchovy in April 1982 similarly started in the north around Rocky Point and Moewe Bay. This continued in May but shifted more south to Palgrave Point in June. A secondary peak in catches occurred between Cape Cross and Walvis Bay as a result of a brief "run" of recruits in late June. In July the usual run of

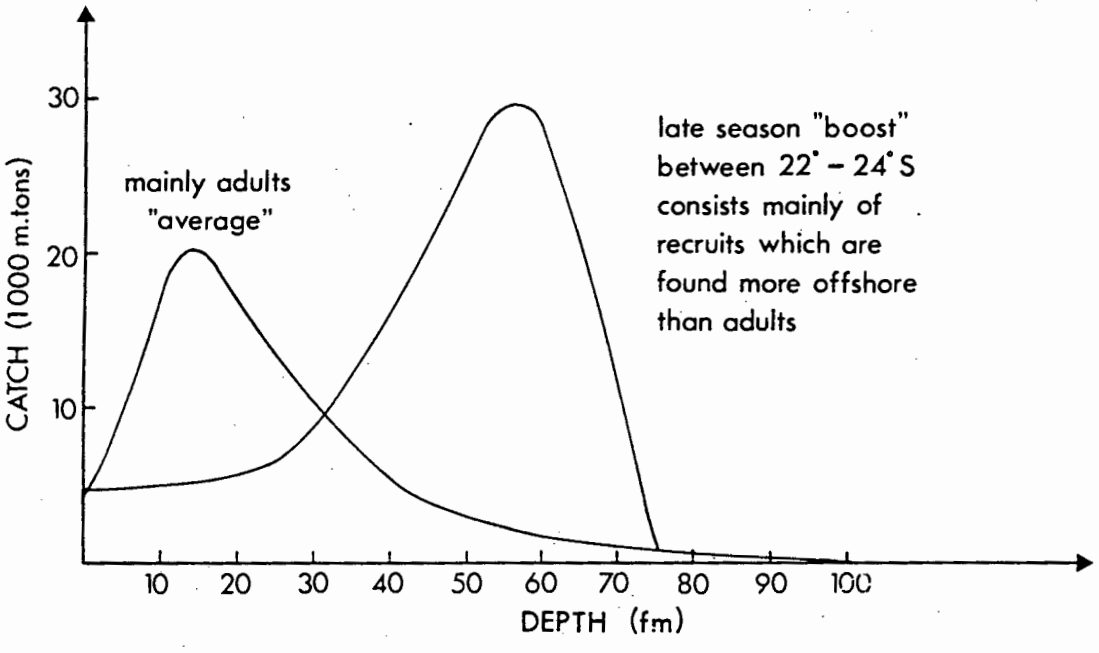


Figure 40 AVERAGE CATCH TOTALS OF a) ADULTS b) RECRUITS (22-24^{0}S)

cf. DEPTH (= DISTANCE OFFSHORE)

recruits had failed and catches again centred on adult fish between Palgrave Point and Rocky Point. A late run of juveniles brought the fishing activity south to Walvis Bay and Cape Cross but a large proportion of the fishing was still based on adult fish north of Palgrave Point.

1983:

The catches comprised 100% adults from Cape Frio to just south of Palgrave Point until the end of April. From May onwards large numbers of recruits were caught off Walvis Bay. South of Walvis Bay no adults were caught and between Hollams Bird Island and Spencer Bay catches were dominated by pre-recruits. Fishing was good throughout the region in June but adult fish were caught mostly either between Cape Cross and Palgrave Point or north of Rocky Point. The typical midwinter "run" of recruits was centred between Cape Cross and Hollams Bird Island but good catches were made as far south as Ichaboe Island near Lüderitz. Small quantities of recruits (8-9cm) were also caught around Moewe Bay and Palgrave Point. July and August showed a steady progression in the catches of recruit fish northward towards Palgrave Point. In August an additional peak of juveniles occurred between Hollams Bird Island and Lüderitz.

1984:

This was a very poor year but a trend was still evident. Fishing started in April from Palgrave Point to Hollams Bird Island. Though more than 50% of that month's catches came from south of Walvis Bay the fish were entirely adults. In May most

of the fish caught were recruits, found between Cape Cross and Hollams Bird Island, but large numbers of adults with some recruits were caught north of Palgrave Point. More recruits from as far south as Spencer Bay were caught in June. After that catches were paltry except for a small influx of recruits off Walvis Bay. This collapse of the fishing was clearly attributable to the El Niño warm event extending down the west coast of Africa bringing warm, tropical waters as far south as Sandwich Harbour, suppressing the effects of upwelling (McLain et al 1985; Thomas and Boyd, 1985) thus inhibiting phytoplankton and zooplankton productivity (Kruger,pers.comm.) and generating less food for anchovies.

1985:

On the whole 1985 was an average year. Spawning was good and occurred much further south than had been the case since 1980 (Le Clus, 1986); the trend towards cooler conditions in summer and winter (McLain, et al, 1985) had reversed and the catch trends of anchovy were average if rather suppressed in comparison with 1978, 1979, 1981 and 1983. Penetration of the Angolan Current in summer was limited to the north of Rocky Point (Boyd et al 1987). Fishing was sustained from March to May by adult fish between Walvis Bay and Cape Frio (Figure 38) and some pre-recruits were caught off Walvis Bay. The fishery completely halted in early May and it is assumed that the stock of anchovy adults had been fished to virtual extinction in April. A flood of juveniles revived the fishery in June. These recruits were caught from Cape Cross to Possession Island (27°S = south of Lüderitz) but mostly between

Walvis Bay and Hollams Bird Island. Late in August and in the beginning of September older recruits (8.0 - 9.5 cm) were caught further northward as far as Palgrave Point while fishing to the south of Walvis Bay ceased to be productive. There was evidence of some adults to the south beyond Spencer Bay where in July the highest catch rates of the season consisted of adults caught over a two week period between Spencer Bay and Lüderitz (Figure 38).

1986:

The 1986 anchovy fishery started in the usual fashion with catches in the north based exclusively on adult fish. Catches were poor the rest of the season and there was no sign of any recruitment shoals north of Hollams Bird Island. No more shoals of adult fish were found after May either. Thus, fishing operations ceased early. This might confirm the foregoing interpretation of virtual extinction of the adult spawning stock in 1985 but sufficient evidence is lacking. Boyd et al (1987) have shown that penetration of the warm Angolan Current water was extensive reaching as far south as 22°S in April. In sharp contrast to the depleted situation of the preceding years, 1987 has, however, produced a strong year class yielding a catch of 376 346 m.tons off Namibia.

There is, thus, a regular trend of autumn and early winter catches of adults only to the north of Palgrave Point. This supports the earlier interpretation, based on acoustic survey records, that "ripe" adults spread out offshore in summer over extensive feeding/spawning areas, mainly between Cape Cross and

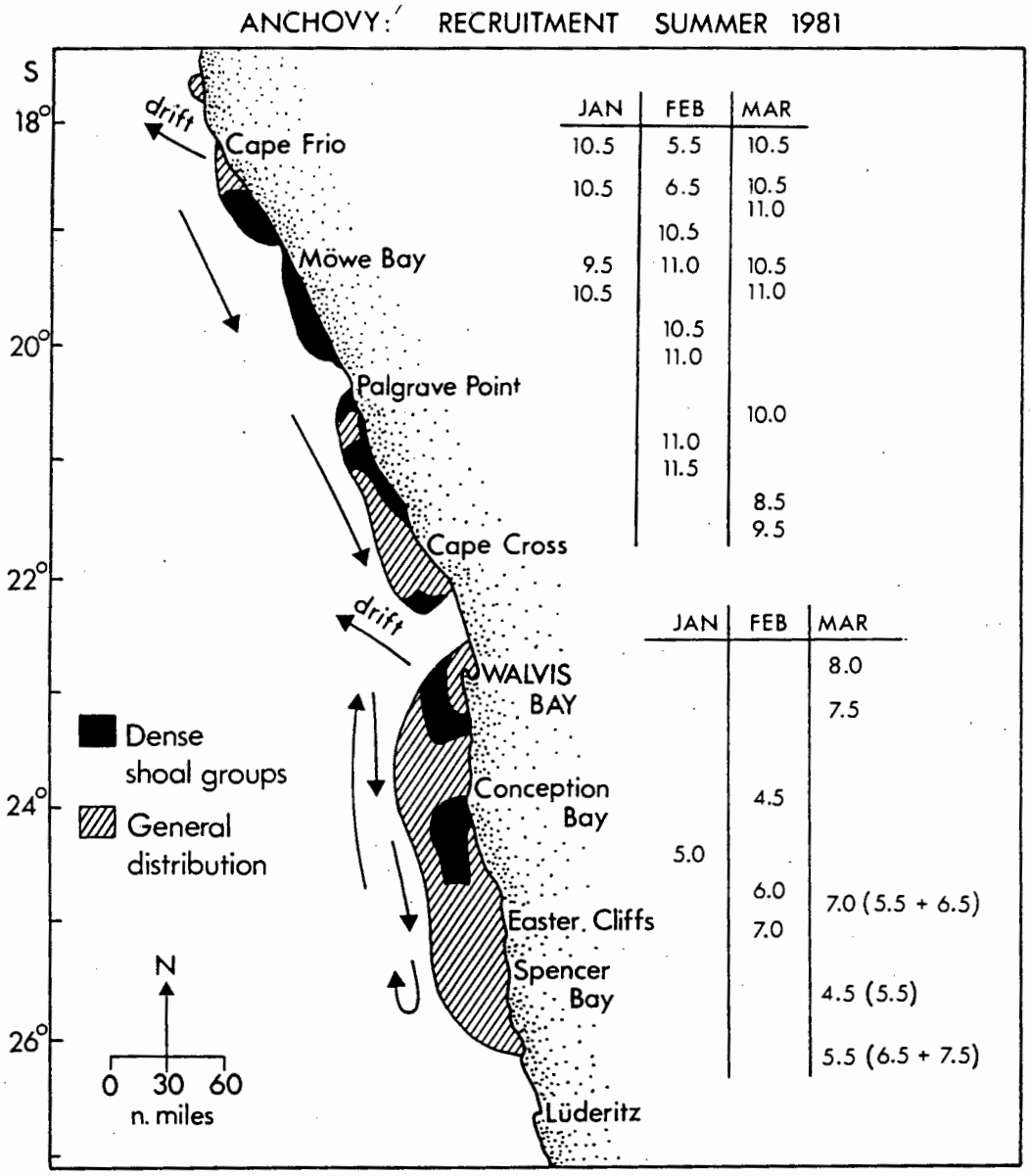


Figure 41 MODAL LENGTH PER MONTH cf. MONTHLY ANCHOVY DISTRIBUTION DERIVED FROM ACOUSTIC AND PURSE-SEINE SURVEYS, 1981

Shaded areas indicate distribution for late summer season.
Dark areas represent high concentrations and consistant occurrence.
Striped areas may have been occupied in only one month of survey.

Walvis Bay (displaced to the north from 1981 to 1983), reverting in autumn and winter to northern, inshore feeding grounds. Similarly, it was argued above that the late summer and autumn distribution of juvenile fish shifts from between Cape Cross and Walvis Bay towards a nursery area between Hollams Bird Island and Lüderitz, after which the recruits migrate northward to winter feeding grounds around Walvis Bay. This interpretation gains further plausibility given the consistent annual "run" of recruits which emmanates from the south and is caught mainly between Cape Cross and Spencer Bay but also further north towards the end of winter. It is also in close agreement with the migration pattern proposed (Cruickshank 1983b) on the evidence of the acoustic survey and length distribution of anchovy recorded in the summer of 1981. This is shown in Figure 41.

DISCUSSION

B.5 STOCK COMPONENTS AND MIGRATION

This discussion will concentrate on the central and northern Namibian stock. Its aim is to synthesise the results of the acoustic surveys and commercial catch data, together with published information from the literature on spawning patterns and pertinent environmental features, and to present them as functional components of the stock. (For discussion of the southern Namibian/Orange River shoals refer to Chapter B.2.). The Namibian anchovy stock is apparently broken up into at least two large sectors (central and northern) based on the peak spawning centres. This, plus the seemingly contradictory water-current regime complicates understanding of the anchovy migratory behaviour. Nonetheless, the results show a fairly consistent pattern off Namibia in all the years studied for both summer surveys and winter commercial fishery statistics.

Figure 42 presents a summary of the near surface oceanography that interacts with anchovy stock components . It is synthesised mostly from Visser et al (1973), O'Toole (1980), Parrish et al (1983), Shannon (1985), Lütjeharms and Stockton (1987) and Boyd et al (1987) as well as other studies reviewed in Chapter B.1. The system is both complex and dynamic with many unpredictable and

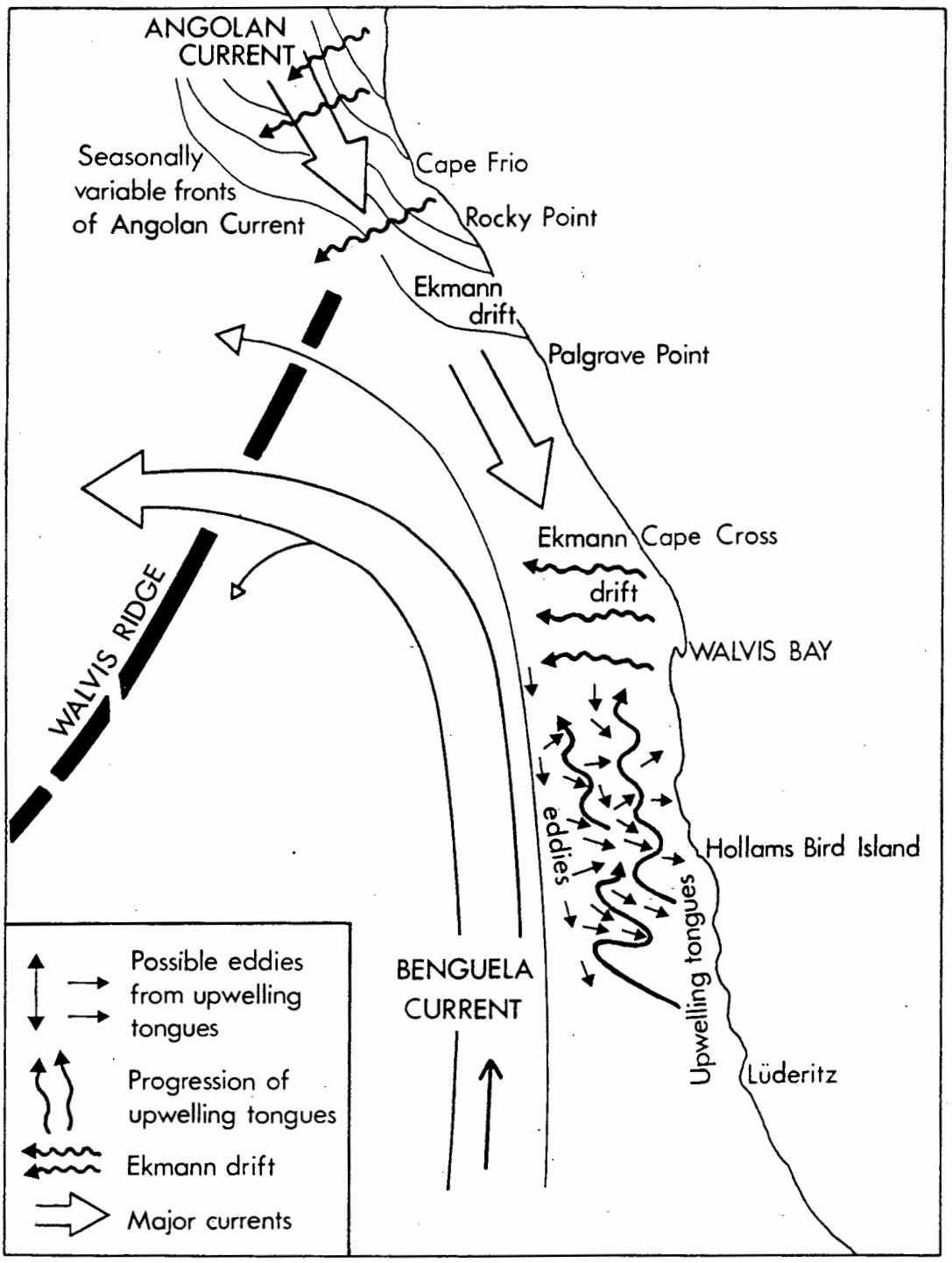


Figure 42 SUMMARY OF NEAR-SURFACE OCEANOGRAPHY OFF NAMIBIA AND MOST LIKELY INFLUENCES ON ANCHOVY DISTRIBUTION AND MIGRATION

References and discussion given in text.

insufficiently understood factors. Nonetheless it is increasingly evident that the near-surface current flows profoundly influence the distribution and movements of the anchovy stock components off Namibia.

Migration theory recognises three main movements by adult and juvenile components of a pelagic fish population (outlined earlier in Figure 1). These include an adult feeding component which migrates between winter-feeding (Ad) and spawning areas(S). The newly spawned component "migrates" passively with the current to a nursery area(N) where food is abundant. They in turn mature and migrate to the adult feeding grounds. It is advantageous for abundant species to avoid competition between the migratory adult and immature components (Harden-Jones 1968). To understand whether the pattern observed in the Namibian anchovy fishery fits this theory the components must be defined.

Adult anchovy spawn from the Cunene River to Hollams Bird Island mainly in late summer (O'Toole 1977; LeClus & Melo 1983). Densest spawning occurs between the Cunene River and Moewe Point and between Walvis Bay and Hollams Bird Island in the south (King 1973a; King & O'Toole 1973; O'Toole 1977; Boyd & Badenhorst 1980; Le Clus 1986). If, according to theory, eggs and larvae drift passively with the current to reach a nursery ground one would expect an offshore accumulation along the northern part of the Namibian coast, i.e. Cape Cross to Palgrave Point and north

of Cape Frio. This is not the case. There is evidence from O'Toole (1977) that anchovy larvae are carried offshore in the wind-driven, surface currents which are associated with the strong upwelling at the coast. As the larvae mature they move inshore (O'Toole 1977; Boyd & Hewitson 1983; Cruickshank 1984). There is also evidence that they move from the far north southward at least as far as Moewe Bay (O'Toole 1977).

It is difficult to determine whether the spawner stock off Cape Frio in the far north forms a separate entity from the rest of the stock or whether it should be considered one with the central region. As already shown, intensive spawning occurs in this area (O'Toole 1977 and Le Clus 1986) with peak abundance of larvae at 60 n. miles due to Ekmann transport, but there is a trend of movement by some older larvae back towards the shore and southward (O'Toole 1977). It is difficult to conceive that larvae, having drifted offshore, can swim back against the Benguela and wind-driven currents. Some early juveniles are found between Cape Frio and Palgrave Point in late summer (Cruickshank 1983b & this study), but their numbers are totally inadequate to account for the consistent, annual spawning intensity in the region. Perhaps this indicates that there is large scale loss of spawner products in some years due to the offshore drift which may then be acting as a stock regulating mechanism. It is possible that the larvae found nearshore and to the south were entrained in intrusions of the Angolan Current. The more larvae that are transported southward

by the Angolan Current the more that may survive and recruit to the stock. Conversely, those larvae not entrained by the current could be lost to the system by drifting further offshore. This could partly explain why the annual recruitment is better in those years when the Angolan Current intrusions in late summer are more extensive (Boyd 1983). The high winds in the area not only affect offshore drift but also cause turbulence which can markedly alter the distribution of food patches. This would have a strong influence on larval survival at the crucial stage when larvae are most sensitive to food availabiity during the first feeding stages. Also, post-larvae in the north would be in competition with- and subject to predation from large shoals of adult anchovy, which are found between Cape Frio and Rocky Point and from Moewe Bay to Palgrave Point in autumn and early winter. It would, therefore, not seem to be an ideal nursery ground between Rocky Point and Palgrave Point.

An alternative possibility is that these juveniles advect southward undetected, in offshore near-surface layers. Limited and circumstantial evidence in support of this comes from acoustic surveys. In March/April 1981 and 1982 some 35 to 45 miles west from Cape Frio to Black Sand Castle there was evidence of an extensive surface layer of very small shoal targets close to the surface which were not successfully sampled with a purse-seine. However, their formation was very similar to that of juvenile anchovy sampled, notably in the same months in 1981, to the south

of Walvis Bay. Further circumstantial evidence is that in autumn and winter at the same distance offshore, there are regularly large numbers of seabirds which feed on small fish and zooplankton at or near the surface. By contrast, the inshore areas are frequented only by a few resident species from the south which can dive deeper and feed on larger-sized fish than the non-resident oceanic species (Crawford et al. 1985). Thirdly, Visser et al (1973) reported a narrow southward flowing current from January to October present between three and twelve miles offshore from Rocky Point to south of Walvis Bay. All large concentrations of fish that they encountered were spread over the width of this counter-current and moving either actively or passively southward. Also, recent revision and new data suggest that a deeper, strong-flowing intrusion of the Angolan Current may penetrate far south below 50m depth, more rapidly and consistantly than previously understood (Boyd, pers.comm.). It may be that post-larvae are transported by this means from the north to the Walvis Bay region beyond the reach of present sampling procedures. Sampling with Bongo and RMT-2 nets in the past 20 years have been restricted to the upper 50m. Thus, it will be necessary to gear further sampling to reach 100m depth. King and Macleod (1976) have shown that larvae and early stage juvenile anchovy are zooplanktophagous. Most of the survey area north of Cape Cross includes a widespread but even distribution of zooplankton, (Kruger 1983; Kruger and Boyd 1984). Therefore, there may be enough food for post-larvae that are being rapidly transported south to where zooplankton and

phytoplankton are more concentrated and patchy, thus encouraging aggregation and shoal formation.

King et al(1979) have shown that temperature has an effect on the rate of anchovy larval development. Based on this Boyd and Badenhorst (1980) speculated that anchovy larvae were unlikely to survive in the cold waters south of Walvis Bay. They proposed an influx of larger larvae from the South-West Cape stock via the Agulhas and Benguela currents. Subsequent studies (Boyd & Hewitson 1983; Cruickshank 1984) have shown that this is unlikely barring exceptional cases. In addition their model is insufficient to explain the vast numbers of anchovy recruits arriving from the south in the annual "run" of recruits in the Walvis Bay region. However, the cold water may well slow the growth rate of some juveniles while others, transported from the north in favourable temperatures, could possibly grow faster given an adequate food supply. This would help to explain some of the contradictions in juvenile length ranges reported in Table 2 and Figures 25,27 & 31.

South of Walvis Bay the distribution of post-larval juveniles determined from acoustic survey records suggest that developing juveniles gather sometimes as far south as Lüderitz in late summer and autumn. They occur in hardly detectable shoals at the surface but, as they grow larger (3.5 to 6.5 cm), they form shoals of increasing size and cohesion (pers. obs.). They feed mainly on zooplankton (King and Macleod 1976) and are found more

offshore than mature fish (Figures 39 & 40). This is possibly due to more favourable temperatures and a patchy availability of required plankton species in ageing upwelled water. Remaining well offshore (15-40 n.miles off), they apparently move northward with the current (Figure 41) to the feeding grounds around Walvis Bay (Cruickshank 1983b & this study). Their diet becomes dominated by phytoplankton (King and Macleod 1976) which is abundant close to the coast and between Cape Cross and Hollams Bird Island, near the upwelling peaks. Thus juvenile anchovy are most abundant through the winter in the Walvis Bay region and grow rapidly, favoured by the water temperatures and abundant food supply. At the same time these fast-growing juveniles (7.0 to 9.5 cm Lc) become available as recruits to the commercial fishery based at Walvis Bay. They apparently move on in spring to join the parent stock in the north as is indicated by the disappearance of the recruits in this region at the end of winter and beginning of spring. Evidence of their feeding activities are given in Thomas et al (1982) and this study (Section C). Adults move to the spawning grounds again in summer. After the spawning season adults move away from the peak spawning and summer feeding areas, concentrating mostly to the north in alternative feeding areas (Section C) close inshore between Moewe Bay and Palgrave Point and between Rocky Point and Cape Frio or to a limited extent to the south between Spencer Bay and Lüderitz. Thus, they would avoid competition with their own offspring.

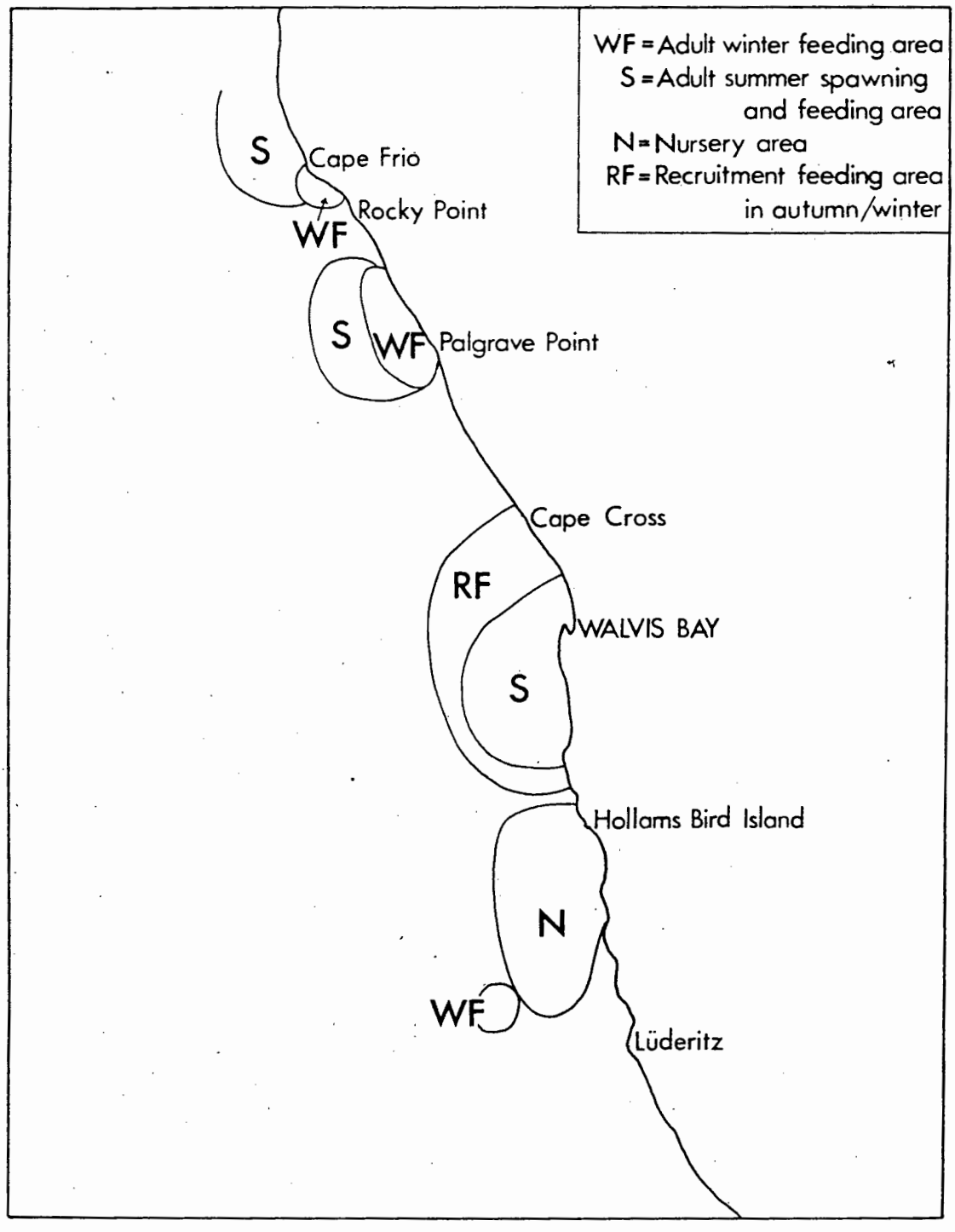


Figure 43 SUMMARY OF ANCHOVY STOCK COMPONENTS OFF NAMIBIA
This is a conceptual presentation. The geographical limits are not necessarily fixed but apparently shift with long-term shifts in broadscale environmental conditions

To summarise, the Namibian anchovy stock can be considered in terms of four basic components (Figure 43) together with the associated current regimes which may be driving the system (Figure 42). The limitations of these data must be recognised against the dynamic and (presently) unpredictable ecosystem off Namibia. The objective here is not to present a final explanation of the migratory patterns of Namibian anchovy but to identify the principle components and thus provide directions for on-going and long-term research. It may be that the four components follow a migration pattern similar to that proposed by Cruickshank (1983b) shown in Figure 41.

The adults form the first component, found in winter feeding areas close inshore between Palgrave Point and Moewe Bay and from Rocky Point to Cape Frio. These groupings are adjacent to some important spawning areas but in the case of the major spawning areas around Walvis Bay, adults must migrate a considerable distance with or against the Benguela Current (Component two). Eggs and larvae are passively removed from the spawning areas in the south and in the north, partly offshore as has been described by King (1973a), O'Toole (1977) and Badenhorst and Boyd(1980), but mostly southward and shoreward (O'Toole 1977; Cruickshank 1984). Yelisarov (1967) has described an offshore counter-current between Walvis Bay and Lüderitz but the full extent, strength and constancy of such a current is as yet unknown. It may be that it is a factor of the offshore eddies of the large upwelling tongues that are

currently being investigated (Lütjeharms and Stockton 1987; Shannon and Agenbag 1987). I accept also that the Angolan Current intrusions can extend as far south as Walvis Bay and that recent information show that these may be more constant and extensive than previously understood (Boyd, pers. comm.). I suggest that these mechanisms could provide sufficient means to entrain spawning products over varying distances southwards, sometimes as far as Lüderitz, in late summer. Between Walvis Bay and Lüderitz various batches of post-larvae feed and undergo initial development in a so-called nursery area (Component three) for the rest of summer. In late summer and autumn, small surface shoals of increasing size and concentrations have been detected 15-40 miles offshore in northward progression from the nursery area to around Walvis Bay. This involves juveniles (4.0 to 9.0 cm) which are fully capable of swimming that distance with the Benguela Current (Component four). During the winter months the recruits remain in the Walvis Bay region, feeding and growing rapidly. In spring, before the adults move out to the spawning areas again, the mature recruits may leave these optimal winter feeding areas and move north of Palgrave Point.

Thus, the passive transport of spawning products to a nursery area and an active recruitment migration of juveniles to a winter feeding area seem to hold true. The requirement for migration to minimise competition for food between adults and juveniles also appears to be met. However, there are still too many data that are

open to conjecture. The stock components and areas proposed here should not be seen as static groupings in specific places but as constantly progressing. These progressions are not necssarily straight south to north migrations but may involve a complex progression of circulating shoal groups. Thomas et al (1982) Cruickshank (1983b & this study: Section C, Figure 44) give evidence of cyclic movements of recruit shoals in the Walvis Bay region (Viljoen 1983) which were associated with feeding. The Namibian system would appear to be too complex to apply the Harden-Jones model simply to the anchovy. An intensive, quantitative study of the post-larval fish extending from the northern spawning areas to the south of the nursery and recruitment areas (in autumn and early winter in particular) is essential to elucidate the confusing issues in their distribution and movements. Also, further details about the extent, strength and regularity of the counter current described by Yelisarov (1967), the upwelling eddies described by Lütjeharms and Stockton (1987) and Shannon and Agenbag(1987) and the southward extent of the Angolan Current are urgently required to further our understanding of the migration patterns of anchovy off Namibia.

SECTION C: DIET AND FEEDING HABITS

1. Introduction

The diet of anchovy off Namibia was investigated by King and Macleod (1976) who showed that phytoplankton was dominant. They also concluded that food items were generally ingested in proportion to availability and that there was no strongly positive selectivity. Limited evidence from catch sampling (Table 18, p125) suggested that zooplankton may be more important in the diet of recruits and adults than King and Macleod had credited. It was felt that because of weaknesses in their analysis further investigation was needed to validate or reject their findings.

King and Macleod collected their samples at night during the pilchard-dominated era when much of the fishing was done at night. At present fishing operations are carried out primarily in daylight when anchovy shoals are more compact and susceptable to fishing. Information on the diet of anchovy during daylight hours may be more relevant to the availability of shoals. King and Macleod based their findings on the numerical frequencies of items in the diet, and not their biomass. It was felt that analyses of both weight and volume fractions as well as numerical freqency might present a different picture of anchovy diet. Furthermore, Davies (1957) suggested that diet could influence distribution of pilchard due to the availability of selected food items. To investigate this

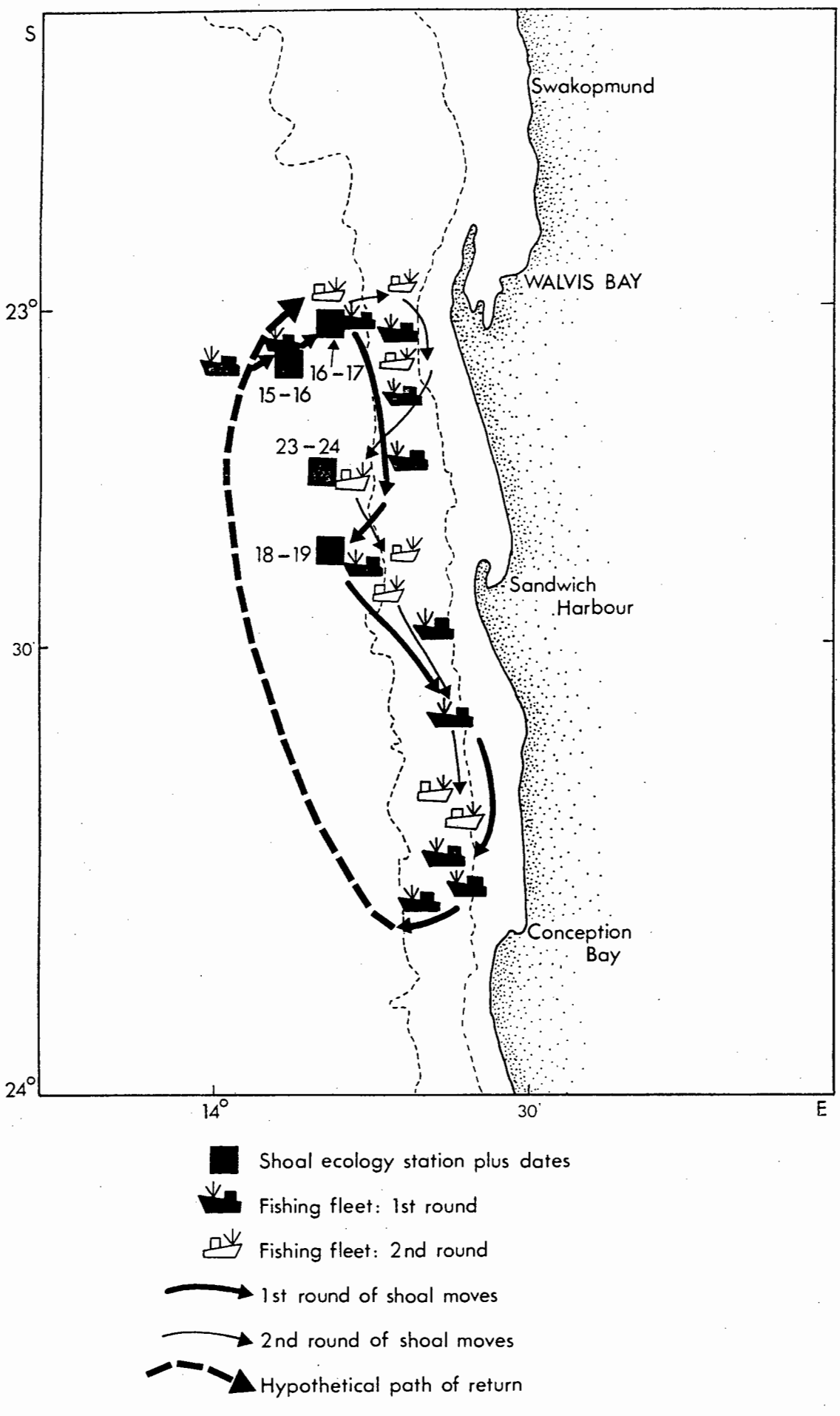


Figure 44 SHOAL FOLLOWING & ENVIRONMENTAL SAMPLING SITES, JUNE 1981

in anchovy it was necessary to compare the diet to the availability of the food items in the surrounding waters and whether fish distribution could be matched to particular areas where preferred food items occur more abundantly.

2. Methods (Outline)

Details of the methods are given in Section A (pp 35-41) but a brief outline is in order here. During shoal-ecology cruises shoal groups of anchovy were located and followed for at least 24 hours (e.g. Figure 44). Random samples of catches were collected from adjacent fishing vessels working the same shoal groups. From these, whole stomachs were extracted and preserved in formalin. Chlorophyll and diatom samples were simultaneously collected from the water column to minimise the effect of plankton patchiness. The available phytoplankton could thus be compared with the fish gut contents for species composition, frequency and relative abundance. The seasons were represented by samples collected during surveys conducted in Winter (June and August 1981); Summer (January 1982) and Autumn (March 1982 and April 1983), at the stations shown in Figure 45.

The results are presented in Tables 3-16. Prey species were grouped here taxonomically according to their genera or order to accentuate the most abundant groups because it was felt that individual species would not show significant frequencies but that larger groups might. The percentage occurrence of the most

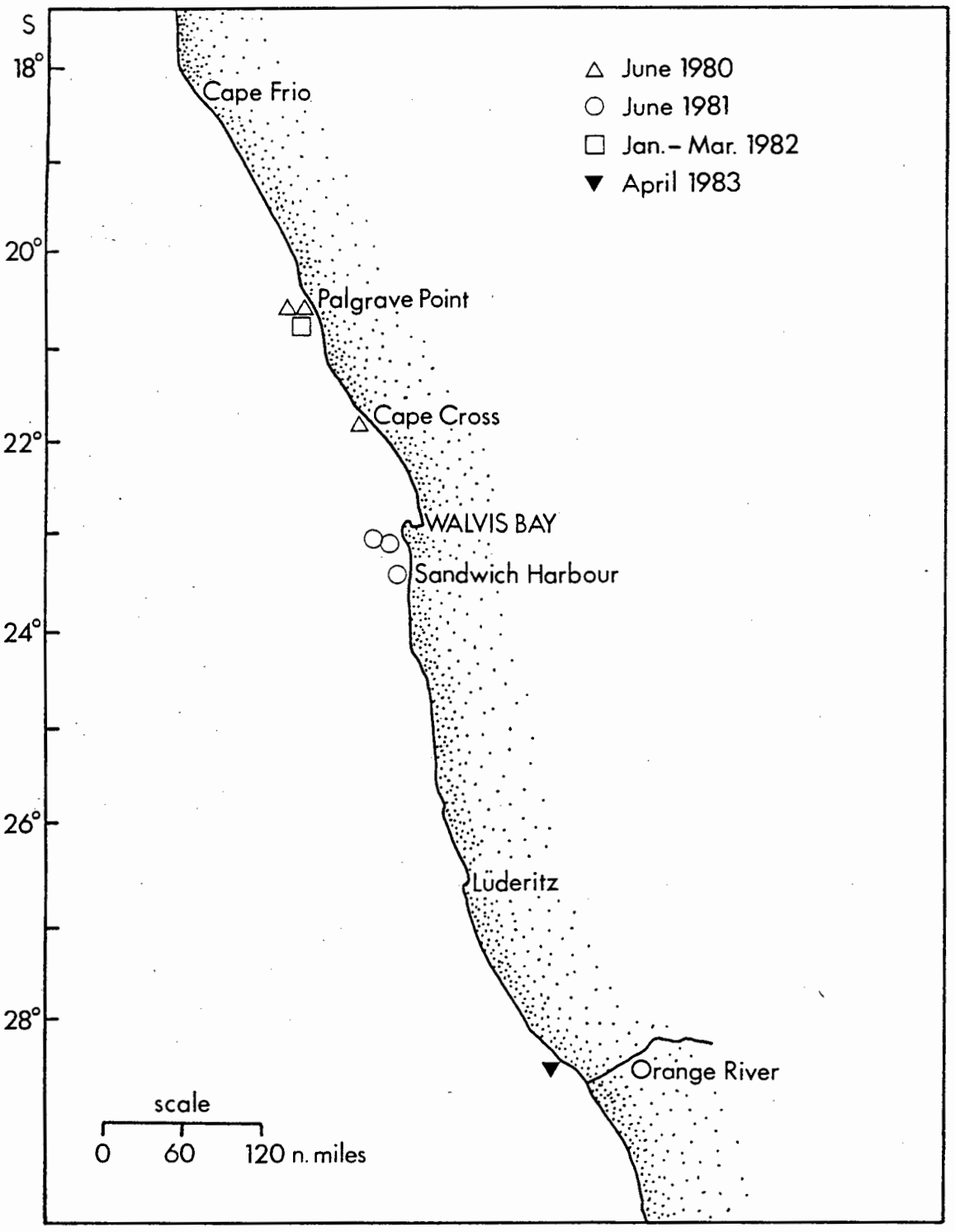


Figure 45 DISTRIBUTION OF SHOAL ECOLOGY SAMPLING SITES,

1980 -1983

prominent orders and genera in the gut contents are also plotted against their percentage occurrence in the environment (Figures 46 to 49). Abundance was quantified in the categories of dominant, abundant, common or scarce as described in "Methods"(p36). Data from commercial catches were analysed geographically and compared to fish distribution to establish: (1) whether there are preferred feeding areas and (2) if feeding frequency coincided with shoal distribution and movements. This information could aid understanding of anchovy shoal migrations off Namibia.

3. Results

(a) Survey Data:

During the cycles of four-hourly hydrological sampling, bottle samples were collected from the water column. These contained the food items immediately available at the same depths and sites from which the fish were sampled. The variances between the water samples collected at different depths ($F^{0.05}= 2.98$) and in different areas ($F^{0.05}= 2.82$, $t^{0.025}= 0.013$) were not statistically significant (20 d.o.f.).

In all, 29 plankton groups were recorded in both stomach contents and water samples, the major contributors being diatoms (13 genera), Dinophyceae (6 genera), Tintinnida (7 genera), Copepoda, Foramenifera and Radiolaria (one genus each). Diatoms were the most important organisms numerically and by frequency in all months sampled. Water samples and stomach contents were dominated

by only seven diatom species or genera of which Chaetoceros spp., Delphineis karstenii, Rhizosolenia setigera, and Nitzschia spp. were the most important. These groups were also prominent in the study by King and Macleod (1976). The rest of the genera, although covering a wide spectrum of species, including some prominent in King and Macleod's study, were almost exclusively rare or scarce in the counts. Dinoflagellates, tintinnids and larger zooplankton were irregular and scarce in the diet much the same as they were in the water column although tintinnids were more frequent in the water. These groups were thus, considered to have been "selected against" or avoided in the diet. Nitzschia spp. were more prominent, and sometimes more frequently present, in the gut content than in the water. Hence, they were considered to be a favoured food item. Rhizosolenia spp. (mostly R.setigera) were similarly more prominent (dominant or abundant) in the guts than in the water column but were generally present in the guts in rough proportion to their frequency in the water samples. But, in March 1982, they were less frequent in the guts than in the water samples.

JUNE 1981

The frequency and relative abundance of organisms found in the near surface zone (0-10m), sub-surface zone (20-30m) and deep zone (50-100m) are presented in Tables 3-5. Tables 6-9 list the frequency and relative abundance of organisms in the stomach contents collected from four sampling sites (Figure 44) over a range of 35 miles from station 01 to 04, which were between 25

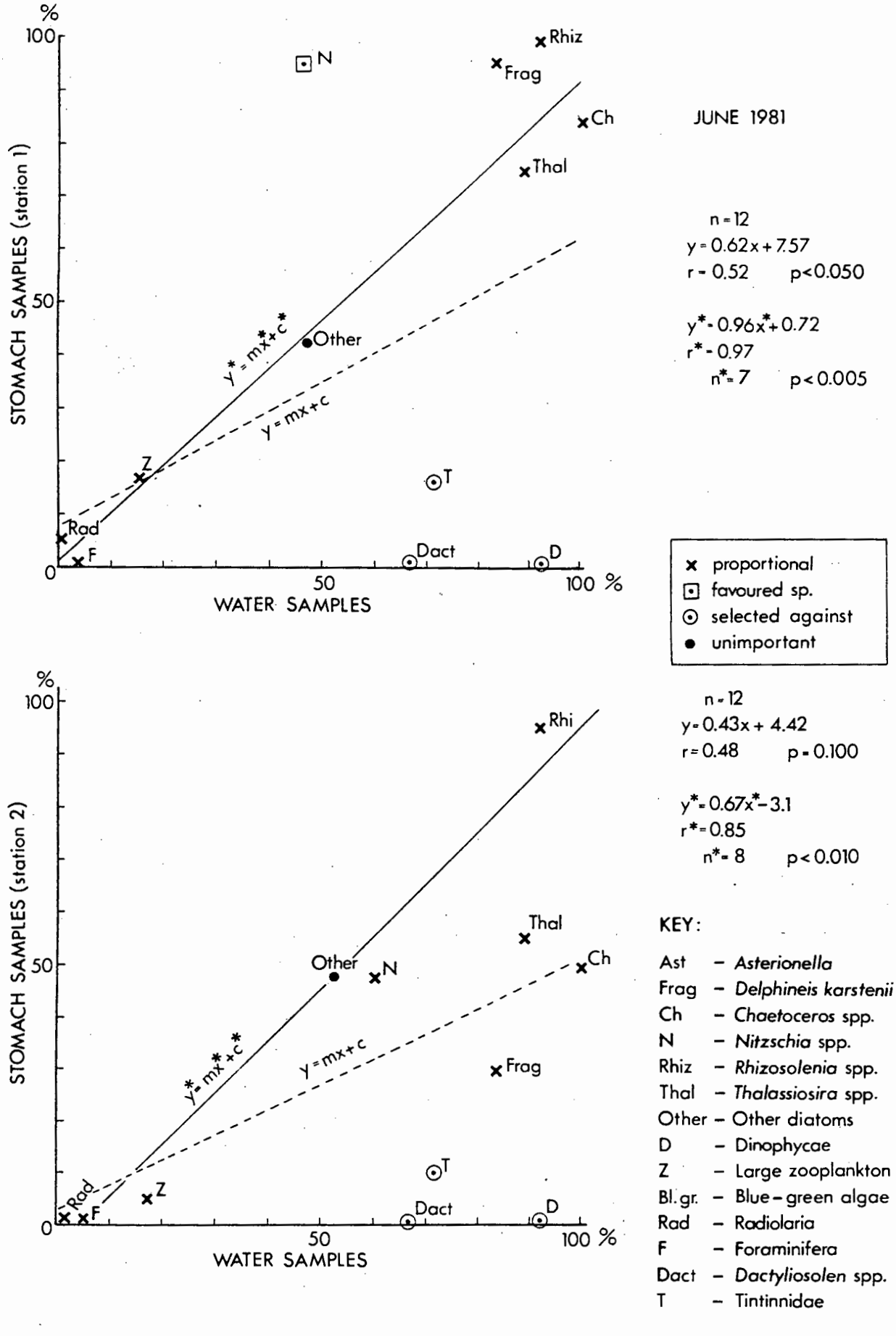


Figure 46 STRAIGHT LINE REGRESSION BETWEEN ORGANISMS IN THE GUT CONTENTS AND THE ENVIRONMENT, JUNE 1981

Regression including all data points produced a graph (dotted line) with a weak correlation co-efficient and low confidence value. A second regression, excluding organisms infrequent (<30%) in the gut content, Nitzschia spp. (highly favoured) and "other diatoms" (irrelevant), produced a graph (solid line) closely fitting a 50:50 ratio of frequency in stomachs and water samples. The correlation co-efficient was good with a high confidence value.

miles west of Pelican Point (23°S) and 10 miles west of Sandwich Harbour (23°25'S). In the first two days of sampling the shoal group slowly shifted about 5 miles nearer to Pelican Point. Although there were signs that fishing pressure from the purse-seine fleet had steadily scattered the large shoals, oxygen depletion and an eruption of hydrogen sulphide may have been strong influences causing the shoal group to move some 19 miles further south. (Kalle 1965, describes herring shoals moving in possible reaction to rapid oxygen depletion.) Another set of samples was collected and when the shoals again moved 6 miles further south. All fish from which stomachs were sampled were $\geq$ 8.0 cms. Fish less than 8.0 cm (Lc) had empty stomachs. For each of these sample sites linear regressions and correlations were calculated for the relationship between the percentage occurrence of various food items in the guts and their percentage occurrence in the samples of the water column (Figures 46-47). In these figures firstly, all the data points were included in the regressions (dotted lines) but, this produced graphs with weak correlation co-efficients and low confidence values. However, second regressions (solid lines) excluded organisms consistantly selected against, ie. they were infrequent (<30%) in the gut content compared to high frequency (>60%) in the water samples. Nitzschia spp., which were often highly favoured, and"other diatoms" (considered an irrelevant group) were also excluded. This regression produced a graph closely fitting a 50:50 ratio of frequency in stomachs and water samples. The correlation co-effic-

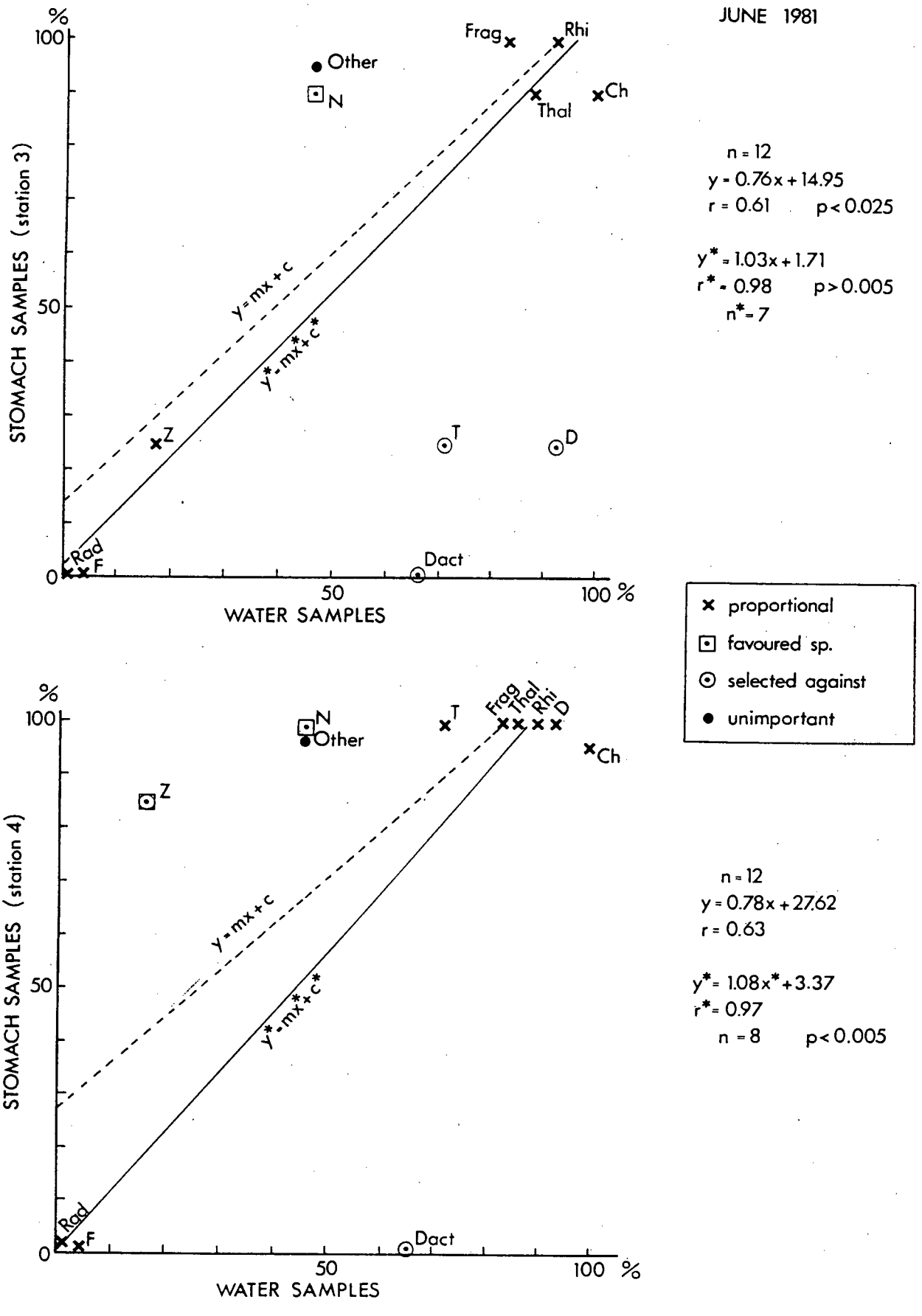


Figure 47 STRAIGHT LINE REGRESSION BETWEEN ORGANISMS IN THE GUT CONTENTS AND THE ENVIRONMENT, JUNE 1981

Regression including all data points produced a graph (dotted line) with a weak correlation co-efficient and low confidence value. A second regression, excluding organisms infrequent (<30%) in the gut content, Nitzschia spp. (highly favoured) and "other diatoms" (irrelevant), produced a graph (solid line) closely fitting a 50:50 ratio of frequency in stomachs and water samples. The correlation co-efficient was good with a high confidence value.

ient was good with, usually, high confidence values ($p < 0.005$). From this a clear inference is gained that Dactyliosolen spp., dinoflagellates and tintinnids are avoided in the diet, Nitzschia spp. are regularly favoured while the other, larger organisms occur in the diet of anchovy in rough proportion to their availability. Consideration is given in the discussion as to whether this selection is achieved by raptorial "choice" or the dimensions of the filtering mechanism being less likely to retain smaller particles. The filtering capabilities of an anchovy larger than 8cms is such that organisms smaller than 0.5mm will generally pass through or be only incidentally caught up. Chain-forming diatoms (e.g. Delphineis spp.) would be taken up in proportion to their availability in the water while larger diatoms such as Nitzschia spp. could be collected by the gill rakers proportional to their availability and could also be raptorially selected, in which case their proportion in the guts would excede that of their availability (King and Macleod 1976, James 1987).

TABLE 3: WATER SAMPLE, GROUP I - June 1981

prey organisms	no. of occur-rences	% frequ.	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Delphineis	20	87.0	45	40	10	5
Dactyliosolen	18	78.3	-	-	77.8	22.3
Thallasiosira	20	87.0	-	5	45	50
Rhizosolenia	20	87.0	-	5	50	45
Chaetoceros	23	100.0	8.7	21.7	60.9	8.7
Nitzschia	8	34.8	-	-	12.5	87.5
Other Diatoms	6	26.1	-	-	-	100
Dinophyceae	12	52.2	-	-	8.3	91.7
Tintinnidae	20	87.0	-	-	20	80
Foramenifera	-	-	-	-	-	-
Large Zooplankton	3	13.0	-	-	66.7	33.3

Depth 0-10m

n = 23 samples

TABLE 4: WATER SAMPLE, GROUP II - June 1981

prey organisms	no. of occur-rences	% frequ.	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce 0.4 ml^{-1}
Delphineis	20	83.3	60	25	15	-
Dactyliosolen	16	66.7	-	12.5	75	12.5
Thalassiosira	21	87.5	-	-	33.3	66.7
Rhizosolenia	22	91.7	-	-	58.9	40.9
Chaetoceros	24	100.0	8.3	37.5	50	4.2
Nitzschia	11	45.8	-	-	27.3	72.7
Other Diatoms	11	45.8	-	-	-	100
Dinophyceae	22	91.7	-	-	-	100
Tintinnidae	17	70.8	-	-	-	100
Foramenifera	1	4.2	-	-	-	100
Large Zooplankton	4	16.7	-	-	50	50

Depth 20-30m

n = 24 samples

TABLE 5: WATER SAMPLES , GROUP III - June 1981

prey organisms	no. of occur-rences	% frequ.	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Delphineis	2	100	-	-	50	50
Dactyliosolen	1	50	-	-	-	100
Thallassiosira	2	100	-	-	-	100
Rhizosolenia	2	100	-	-	100	-
Chaetoceros	2	100	-	-	-	-
Nitzschia	2	100	-	-	100	-
Other Diatoms	2	100	-	-	50	50
Dinophyceae	2	100	-	-	-	100
Tintinnidae	1	50	-	-	-	100
Foramenifera	-	-	-	-	-	-
Large Zooplankton	-	-	-	-	-	-

Depth 50-100m

n = 2 samples

TABLE 6: STOMACH CONTENTS - June 1981

prey organisms	Number of occurrences	% frequency	Dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Delphineis	18	95.0	27.8	61.1	11.1	-
Rhizosolenia	19	100.0	36.8	47.4	10.5	5.3
Nitzschia	18	95.0	-	5.6	61.1	33.4
Chaetoceros	16	84.2	-	-	25	75
Thallassiosira	14	73.7	-	-	42.9	57.1
Other diatoms	8	42.1	-	-	-	100
Dinophyceae	-	-	-	-	-	-
Nanoplankton	11	57.9	18.2	27.3	45.5	9.1
Tintinnidae	3	15.8	-	-	-	100
Radiolaria	1	5.3	-	-	-	100
Large Zooplankton	3	15.8	-	-	-	100

Stn. 001/ A8-A28

Position. West of Pelican Point

Number of stomachs = 20

TABLE 7: STOMACH CONTENTS - June 1981

prey organisms	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <0.4 ml^{-1}
Delphineis	6	30	-	-	83.3	16.7
Rhizosolenia	19	95	-	5.3	52.6	42.1
Nitzschia	12	60	-	-	25	75
Chaetoceros	10	50	-	-	10	90
Thalassiosira	11	55	-	-	18.2	81.8
Other diatoms	10	50	-	-	-	100
Dinophyceae	-	-	-	-	-	-
Nanoplankton	7	35	-	-	100	-
Tintinnidae	2	10	-	-	-	100
Radiolaria	-	-	-	-	-	-
Large Zooplankton	1	5	-	-	-	100

Stn. 002/ A4-A24

Position: West of Pelican Point

Number of stomachs = 20

TABLE 8: STOMACH CONTENTS - June 1981

prey organisms	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Delphineis	20	100	20	70	10	-
Rhizosolenia	20	100	65	35	-	-
Nitzschia	18	90	-	11.1	72.2	16.7
Chaetoceros	18	90	-	16.7	72.2	11.1
Thalassiosira	18	90	-	-	55.6	44.4
Other diatoms	19	95	-	-	63.2	36.8
Dinophyceae	5	25	-	-	-	100
Nanoplankton	5	25	-	-	100	-
Tintinidae	5	25	-	-	-	100
Radiolaria	-	-	-	-	-	-
Large Zooplankton	5	25	-	-	-	100

Stn. 003/ A5-A25

Position: West of Sandwich Harbour

Number of stomachs = 20

TABLE 9: STOMACH CONTENTS - June 1981

prey organisms	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Delphineis	20	100	85	15	-	-
Rhizosolenia	20	100	100	-	-	-
Nitzschia	20	100	-	15	80	5
Chaetoceros	19	95	-	42.1	57.9	-
Thalassiosira	20	100	-	10	90	-
Other diatoms	20	100	-	30	65	5
Dinophyceae	20	100	-	-	90	10
Nanoplankton	-	-	-	-	-	-
Tintinnidae	20	100	-	-	20	80
Radiolaria	-	-	-	-	-	-
Large Zooplankton	17	85	-	-	29.4	70.6

Stn. 004/ A1-A20

Position: West - between Walvis Bay and Sandwich Harbour

Number of stomachs = 20

AUGUST 1981

Anchovy shoals were scarce and commercial fishing activity much less than in June. It was thus difficult to find suitable size shoal groups on which at least some purse-seine vessels were operating. Only one such group was located and followed for a 24-hour cycle of environmental sampling. Much the same species composition as in June was found in the water and stomach contents with the same major genera of diatoms represented (Tables 10-11 and Figure 48). Chaetoceros spp., Nitzschia spp.and Thalassiosira spp. were the most important. Nitzschia spp. showed enhanced abundance (dominant) in the stomachs over their availability. The reverse is true for Rhizosolenia spp. which were always scarce in the gut contents, with 42.1% occurrence, in marked contrast to their abundance in the surrounding water. This negative ratio contrasts with the dominant role of Rhizosolenia spp. in June 1981. Dinoflagellates were more frequent in the gut contents but still very low in proportion to availability. Zooplankton were much more frequent in the watrer samples but, together with other groups such as Nanoplankton, blue-green algae and coccolithophores, remained insignificant portions in the guts. Even after these extreme data points were eliminated, the regression line was still weakly matched ($r^*= 0.58$, $p<o.100$) to the data points such as the inconsistently low percentages of eg. Delphineis karstenii and Rhizosolenia setigera.

KEY:

Frag – *Delphineis karstenii*
Ch – *Chaetoceros* spp.
N – *Nitzschia* spp.
Rhiz – *Rhizosolenia* spp.
Thal – *Thalassiosira* spp.
Dact – *Dactyliosolen* spp.
Other – Other diatoms
D – Dinophycae
T – Tintinnidae
F – Foraminifera
Rad – Radiolaria
Z – Large zooplankton
Cocc. – *Coccolithophorids*
Nano – Nanoplankton

AUGUST 1981

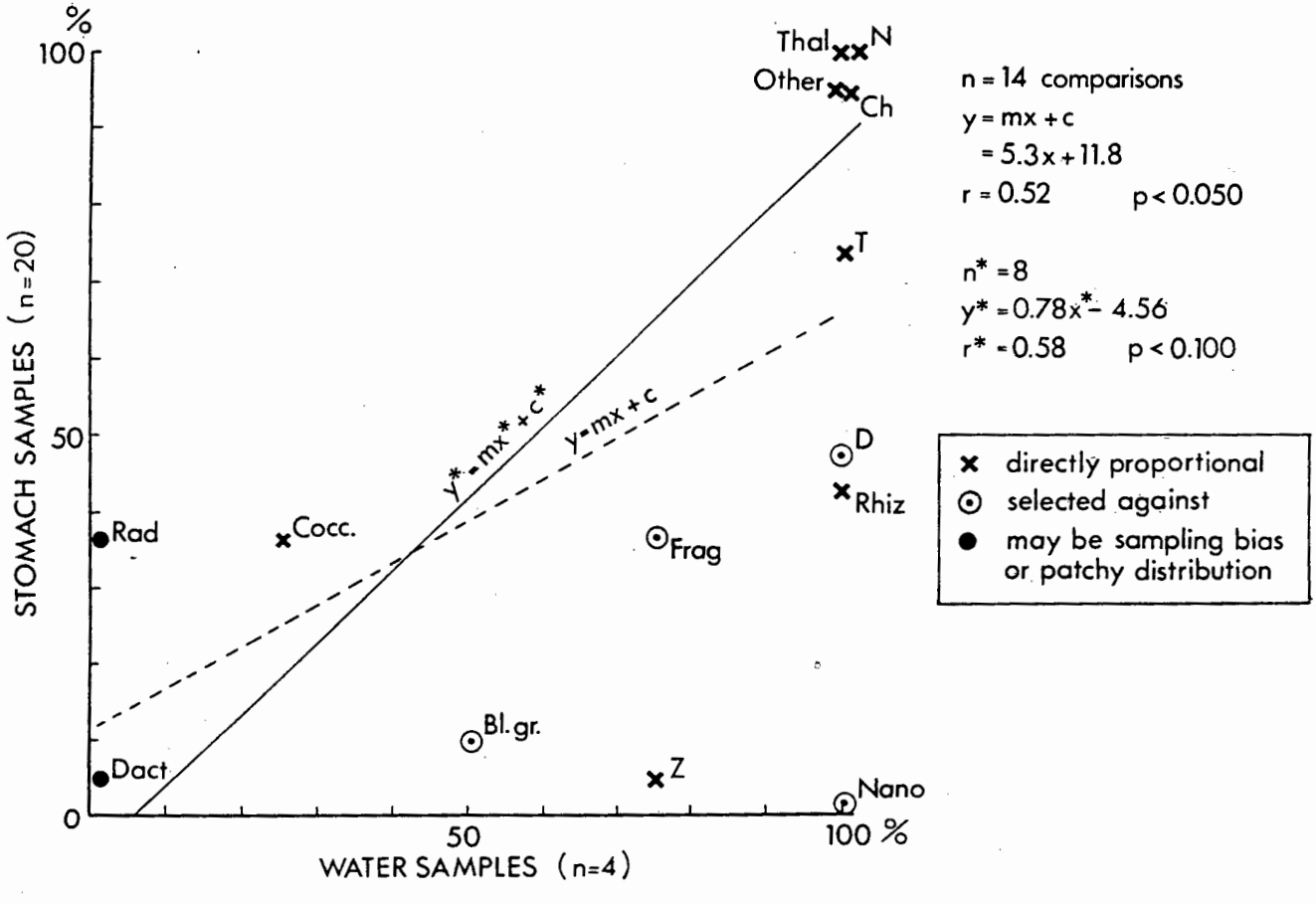


Figure 48 STRAIGHT LINE REGRESSION BETWEEN ORGANISMS IN THE GUT CONTENTS AND THE ENVIRONMENT, AUGUST 1981

Regression including all data points produced a graph (dotted line) with a weak correlation co-efficient and low confidence value. A second regression, excluding organisms infrequent (<30%) in the gut content, Nitzschia spp. (highly favoured) and "other diatoms" (irrelevant), produced a graph (solid line) closely fitting a 50:50 ratio of frequency in stomachs and water samples. The correlation co-efficient was good with a high confidence value.

TABLE 10: WATER SAMPLES - August 1981

prey organisms	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Chaetoceros	4	100	100	-	-	-
Rhizosolenia	4	100	50	50	-	-
Thallasiosira	4	100	25	50	-	25
Delphineis	3	75	33.3	33.3	-	33.3
Nitzschia	4	100	-	-	25	75
Other diatoms	4	100	-	-	75	25
Dinophyceae	4	100	25	75	-	-
Blue green Algae	2	50	-	-	50	50
Nanoplankton	4	100	-	25	25	50
Tintinnidae	4	100	-	50	50	-
Radiolaria	1	25	-	-	-	100
Large Zooplankton	3	75	-	-	33.3	66.7

TABLE 11: STOMACH CONTENTS - August 1981

prey organisms	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <0.4 ml^{-1}
Chaetoceros	18	94.7	50	22.5	27.5	-
Nitzschia	19	100.0	47.4	47.4	5.3	-
Delphineis	7	36.8	14.3	14.3	28.6	42.9
Thallasiosira	19	100.0	5.3	21.1	57.9	15.8
Rhizosolenia	8	42.1	-	-	-	100
Dactyliosolen	1	5.3	-	-	-	100
Coccolithophores	7	36.8	-	14.3	14.3	71.4
Other diatoms	18	94.7	-	33.3	55.5	11.1
Dinophyceae	9	47.4	-	-	-	100
Blue green Algae	2	10.5	-	-	50	50
Tintinnidae	14	73.7	-	-	7.1	92.8
Radiolaria	7	36.8	-	-	-	100
Large Zooplankton	1	5.3	-	-	-	100

n = 19 stomachs

JANUARY - MARCH 1982

During the summer distribution survey in 1982, stomach contents were examined from adult anchovy collected in the coastal waters between Rocky Point and Palgrave Point (19°S to 20°30's). Fish sampled in February all had empty stomachs and only three out of 25 fish from the subsample collected in January had full stomachs. Results from these months are therefore not considered further. The results for March are presented in Tables 12 and 13. Due to the lack of facilities on the fishing vessel used to collect the samples, no bottle samples for the water column were collected *in situ*. During these months diatoms were sampled from the research vessel *Benguela* which was involved in the same survey in the close vicinity. No significant differences were distinguishable between these results and those obtained for the other months and areas reported on in this study. This and a linear regression factor of $r = 0.92$ (Figure 49) lend confidence to the comparison despite a slight difference in sample collection. The same major groups predominated but *Rhizosolenia* spp. were significantly absent from the guts. The Dinophyceae, although frequent but "scarce" in the water, were more frequent and abundant (18% dominant) in the stomachs than in other samplings. However, this and previous studies by Davies (1957) and King and Macleod (1976) have shown that dinoflagellates are not an important food item for pilchard and anchovy. Their prominence here is assumed to represent a dense, patchy availability. *Asterionella japonica* were favoured items here, as also reported by King and Macleod (1976), were

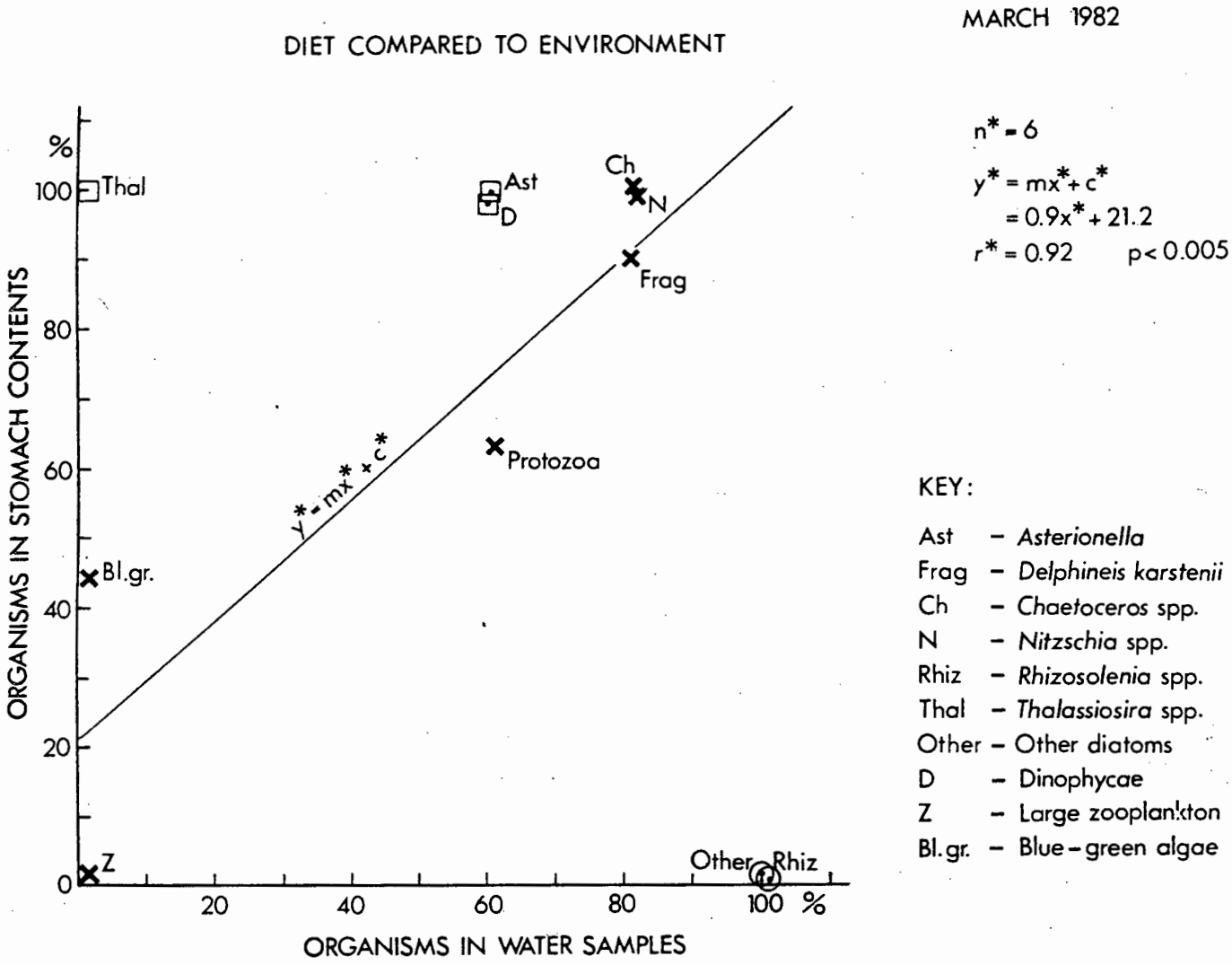


Figure 49 STRAIGHT LINE REGRESSION BETWEEN ORGANISMS IN THE GUT CONTENTS AND THE ENVIRONMENT, MARCH 1982

Regression including all data points produced a graph (dotted line) with a weak correlation co-efficient and low confidence value. A second regression, excluding organisms infrequent (<30%) in the gut content, Nitzschia spp. (highly favoured) and "other diatoms" (irrelevant), produced a graph (solid line) closely fitting a 50:50 ratio of frequency in stomachs and water samples. The correlation co-efficient was good with a high confidence value.

TABLE 12: WATER SAMPLES - March 1982

prey organisms	number of occurences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Rhizosolenia spp.	25	100	-	-	20	80
Thallassisira sp.	-	-	-	-	-	-
Delphineis sp.	20	80	-	40	40	20
Chaetoceros spp.	20	80	60	-	-	40
Nitzschia spp.	20	80	-	-	10	90
Asterionella sp.	15	60	-	-	-	100
Other Diatoms	25	100	-	-	40	60
Dinophyceae	15	60	-	-	-	100
Cyanophyceae	-	-	-	-	-	-
Protozoa	15	60	-	-	-	100
large Zooplankton	-	-	-	-	-	-

n = 25 samples

TABLE 13. STOMACH CONTENTS - March 1982

prey organisms	number of occurences	% frequency	dominant >50 ml^{-1}	abundant & common 0.4-50 ml^{-1}	scarce <o.4 ml^{-1}
Thallassiosira	25	100	72.7	27.3	-
Delphineis	23	92	27.3	54.5	9.1
Chaetoceros spp.	25	100	36.4	54.5	9.1
Nitzschia spp.	25	100	-	100	-
Asterionella sp.	25	100	-	81.8	18.2
Dinophyceae	25	100	18.2	-	81.8
Cyanophyceae	11	44	-	9.1	90.9
Protozoa	16	64	-	-	100

n = 25 stomachs

otherwise insignificant in this study. Thalassiosira spp. were generally injested in proportion to availability, but in March 1982 they were highly favoured (73% dominant) food items. Once again dense, highly localised availability is assumed responsible and attention to these patchy items may explain the apparent "avoidance" of Rhizosolenia spp., which were frequent but not abundant in the water.

APRIL 1983:

A fairly large shoal group (10x45 miles) of juvenile anchovy (7.5-8.5 mm Lc) was detected from the Orange River mouth to Chamais Bay (about 28o to 28o 35' S). Analysis of bottle samples collected in association with these shoals (Tables 14, 15 & 16) found basically the same planktonic biota as was recorded in the north in the winter of 1981 and summer of 1982 (Tables 10-13) with a few differences. Delphineis karstenii was half as frequent and much less abundant. The Chaetoceros spp. were less frequent than in either June or August off Walvis Bay but were more abundant. Nitzschia spp. showed a similar frequency but were also much more abundant and often dominant. Rhizosolenia spp. were present in roughly the same frequency and abundance. Large zooplankton were not found in any of the samples. This is not surprising as they were only found in low concentration in the displaced volume samples from N50V net vertical hauls and in surface, horizontal Neuston net hauls, they were insignificant or absent in the area of anchovy distribution. However, because all anchovy stomachs examined were found to be empty, no direct

comparison can be made. That the sampling site was nonetheless in an anchovy feeding area can be deduced from the regular accumulation of post-larvae to recruit size each year in the area (Boyd and Hewitson 1983; Cruickshank 1984 and this study).

Generally then, it is clear that large (>0.5 mm), chain-forming (>1 mm) diatoms were the dominant (>50 ml/l and 50 - 100% frequency) food items in the anchovy diet. Being abundantly available (>70% frequency) off Namibia and readily ingested because of their size and grouping, they show strong correlation (r= 0.9 - 1.0) between their percentage occurrence in the gut contents and the environment. Certain genera of diatoms are most often taken in the diet but not always directly proportional numerically to their abundance in the the water. The pattern also shows inconsistencies such as the apparent avoidance of Rhizosolenia spp.in March 1982 in contrast to other months when they occurred in direct proportion to availability. Other food items were clearly selected against in that they were generally insignificant (<0.4ml/l) in the diet despite sometimes high total frequency (50-100%) in the water column. This could have occurred due to selective feeding on larger food particles, or if the gill-raker filtering mechanism, as described by King and Macleod (1976) was too course (0.3-0.5mm) to retain the smaller prey sizes (<0.5mm) they could have escaped rather than have been avoided. Larger particles (>0.8mm) would have been retained in proportion to their availability (>70% frequency) as was generally the case in this study.

TABLE 14: WATER SAMPLE, GROUP I - April 1983

prey organisms	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Nitzschia	14	100	64.3	7.1	14.3	14.3
Delphineis	7	50.0	-	57.1	28.6	14.3
Rhizosolenia	12	85.7	8.3	25	50.0	16.7
Chaetoceros	10	71.4	60	20	20	-
Asterionella	5	35.7	20	20	20	40
Thallasiosira	7	50.0	-	85.7	14.3	-
Dactyliosolen	5	35.7	-	-	60	40
Other diatoms	11	78.6	-	-	72.7	27.3
Dinophyceae	4	23.6	-	-	-	100
Tintinnidae	5	35.7	-	-	-	100
Radiolaria	1	7.1	-	-	-	100

Depth 0 - 10 m

n = 14 samples

TABLE 15: WATER SAMPLE, GROUP II - April 1983

prey organisms	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <0.4 ml^{-1}
Nitzschia	14	100.0	42.9	14.3	35.7	7.1
Delphineis	6	42.9	16.7	33.3	33.3	16.7
Rhizosolenia	11	78.6	-	27.3	45.5	27.3
Chaetoceros	9	64.3	66.7	22.2	11.1	-
Asterionella	5	35.7	-	40	40	20
Thallasiosira	7	50.0	-	28.6	59.1	14.3
Dactyliosolen	8	57.1	-	37.5	25	37.5
Other diatoms	13	92.9	-	-	46.2	53.8
Dinophyceae	2	14.3	-	-	-	100
Tintinnidae	2	14.3	-	-	-	100
Radiolaria	5	35.7	-	-	-	100

Depth 20 - 30 m

n = 14 samples

TABLE 16: WATER SAMPLES, GROUP III - April 1983

prey organism	Number of occurrences	% frequency	dominant >50 ml^{-1}	abundant 20-50 ml^{-1}	common 0.4-20 ml^{-1}	scarce <o.4 ml^{-1}
Nitzschia	12	92.3	41.7	25	16.7	16.7
Delphineis	5	38.5	-	40	40	20
Rhizosolenia	7	53.8	-	-	42.9	57.1
Chaetoceros	6	48.2	66.7	16.7	16.7	-
Asterionella	5	38.5	-	40	20	40
Thallasiosira	8	61.5	-	-	37.5	62.5
Dactyliosolen	5	38.5	-	-	40	60
Other diatoms	10	76.9	-	10	10	80
Dinophyceae	-	-	-	-	-	-
Tintinnidae	1	7.7	-	-	-	100
Radiolaria	2	15.4	-	-	50	50
Blue green Algae	1	7.7	-	-	100	-

Depth 50 - 100 m

n = 13 samples

PHYTOPLANKTON DISTRIBUTION cf CHLOROPHYLL MAXIMA

Maximum species diversity was found at 20 meters and secondarily at 10 meter depth. Similarly, counting each occurrence of a species, there was a total of 391 occurrences of all species from 0-100 m in 49 samplings. The percentage frequency of these occurrences was also greatest at 20 meters, then at 10 meters (Table 17).

Comparison of results between chlorophyll data and phytoplankton samples collected at corresponding stations in June 1981 showed close correspondence between depth of the chlorophyll maxima and the maximum cell count at 40 stations (Tables 17 & 18). Two stations showed only a weak match with highest cell count found either 10 meters above or below the chlorophyll maximum layer. At the remaining six stations, comparisons were inconclusive. Therefore chlorophyll maxima are confirmed here as indicators of densest phytoplankton concentrations. This is in agreement with the findings of other authors in the Benguela system off the RSA (Brown and Hutchings 1985, and pers comm.) and is an important consideration when discussing anchovy feeding and distribution relative to chlorophyll maxima.

TABLE 17: PHYTOPLANKTON/CHLOROPHYLL MAXIMA/DEPTH - June 1981

Depth (m)	%frequency of occurrence of species	number of Genera	%frequency of chlorophyll max.
0	18.7	14	15.5
10	28.9	19	34.4
20	32.2	20	43.8
30	15.4	16	6.3
50	2.3	9	-
100	2.5	10	-

TABLE 18: PHYTOPLANKTON NUMBERS CF. DEPTH - June 1981

Depth	Cell Count per litre	number of samples
0	$931X10^3$	10
10	$1390X10^3$	15
20	$1635X10^3$	17
30	$639X10^3$	7
50)	$73X10^3$	2
100)		

3. RESULTS

(b) Commercial Catch Sampling

STOMACH FULLNESS AND CONTENT

No differences between the sexes were determined from the data available on the diet from regular sampling of the landings of anchovy at Walvis Bay carried out by Sea Fisheries personnel. The results are thus presented in Table 19 without distinction between the genders although more appropriate sampling procedures might show valid differences.

In August and October 1979, January, April, May and June 1981 zooplankton were prominent in stomach contents (e.g. 86.7% of stomachs sampled in January 1981). In total, 15.3% of anchovy stomachs examined in the 1981 season contained zooplankton and in 21.2% phytoplankton only were positively identified. This initially led me to believe that the findings of King and Macleod (1976) that phytoplankton dominate the gut contents might be incorrect or no longer true off Namibia. From 1982 to 1985, however, zooplankton were either totally absent or constituted a small fraction of the gut contents. Table 19 shows that of 20709 anchovy stomachs examined from the commercial catches between August 1979 and August 1985 only 7.2% contained zooplankton either wholely or mixed with phytoplankton; 76.9% contained solely phytoplankton (protozoans would have been lumped with phytoplankton in this method) while 15.2% were indeterminate. If the latter are excluded then these values increase such that

TABLE 19: STOMACH CONTENTS FROM COMMERCIAL CATCHES

Year	total number of stomachs	number of stomachs with: Phytopl. 100% (by volume)	Zooplankton 25%	50%	75%	number with undetermined contents
1979	524	74	350	100	-	-
1980	4856	3577		198	-	1081
1981	3392	739		536	-	2217
1982	3537	3537	-	-	-	-
1983	3400	3400	-	-	-	-
1984	1551	1501	-	-	50	-
1985	3043	2796	-	-	247	-
$6^1/_2$ YRS TOTAL	20709	15930		1481		3298
% 1979-85		76.9		7.2		15.9

of the 17411 stomachs for which contents were identified, 8.5% contained only zooplankton or a mixture and 91.5% had only phytoplankton. Separating the figures for adults and recruits showed no marked difference between immature (6.0- 9.5cm) and adult animals. There was a slight seasonal trend in that zooplankton were mostly included in the diet in late winter (July-August) and to a lesser extent in late Autumn (March-May).

Analysis of feeding data according to geographic area in the catch statistics for Namibia from 1980-1985 indicates that there are two important feeding areas for immature and adult anchovy. These feeding areas may play a major roll in the migration patterns of anchovy off Namibia. Table 20 shows the distribution per 20-mile grid-square of 466 samples of 50 stomachs each collected over the period 1980 to 1985. These are totalled for each degree of latitude for easier presentation in the table.

The most important feeding area is between latitudes 22°S and 24°S and there is another major feeding area north of 21°S (Ambrose Bay to Cape Frio) with a peak between 19°S and 20°S latitudes _viz_ Rocky Point to Dune Point. The break down into zones according to distance from the coast shows that not only is the major feeding area between 22°S and 24°S latitudes but that it also extends somewhat offshore. The feeding area to the north is confined to the waters close to the coast. This is in accordance with the pattern of phytoplankton distribution (Kruger 1983) and

anchovy distribution described by Cruickshank (1983a & herein).

As an indicator of feeding periodicity the data on stomach fullness were analysed in four-hourly periods of the day and night and per 20-mile grid square. The following trends were noted: In the early morning (00-0400hrs) full stomachs were slightly more frequent close inshore but there was little difference between the zones. At dawn (0400-0600hrs) twice as many full stomachs were collected from the nearshore zone compared with close inshore. Late afternoon (1600-2000) feeding was high for the inshore and nearshore zones but decreased markedly offshore. At night time (2000-2400) feeding was low in all three zones but was slightly higher inshore. Thus, in the inshore zone feeding predominated from the late morning to late afternoon periods. In the nearshore zone full stomachs were equally frequent at dawn and in the late morning which suggests predawn feeding. The late afternoon also forms a major period of feeding in this zone. In the offshore zone the late morning and late afternoon periods totally dominated the feeding cycle with zero full stomachs at dawn and very few during the night hours.

Clearly anchovy do not feed exclusively at night but at all times of day, particularly in the near- and inshore zones. It is difficult to draw any further conclusions regarding feeding behaviour from these data. Caution is needed because they may

TABLE 20: FREQUENCY OF STOMACH FULLNESS CF. LATITUDE 1980-85

latitude	number of samplings	percentage total	frequency of full stomachs: inshore	near-shore	off-shore
18-19	38	8.2	7.7	0.4	-
19-20	74	15.9)27%	7.9	4.9	3.0
20-21	51	10.9)	7.5	3.2	0.2
21-22	41	8.8	5.6	2.8	0.4
22-23	117	25.1)41%	10.9	11.0	3.2
23-24	73	15.7)	2.8	10.8	2.1
24-25	41	8.9	3.9	3.9	1.1
25-26	26	5.6	2.4	1.3	1.9
26-27	3	0.6	0.6	-	-
27-28	0	0.0	0.0	-	-
28-29	2	0.4	0.4	-	-
total	466	100	49.7	37.4	11.9

Though based on 20-mile grid-squares these figures have been totalled for each degree of latitude South.

inshore = 0 - 20 miles ; nearshore = 20 - 40 miles and offshore = > 40 miles

reflect a fishing bias towards catching at dawn and late afternoon and the fishermen's distrust of most offshore positions at night. However, Kruger and Cruickshank (1982) also showed the importance of late afternoon feeding. It is clear though that feeding patterns of anchovy off Namibia (indicated by stomach fullness) correspond to their inshore or nearshore shoaling behaviour and the higher availability of phytoplankton inshore. The selection of midday for the sampling of stomach contents in relation to environmental conditions (see methods) is thus justified as being representative of the diet.

4. DISCUSSION

De Ciechomski (1967) has stated that the diet of the Argentinian anchovy (Engraulis anchoita) is dependent on the patterns of plankton dispersal. Koginovskaia (1934, quoted in Loukashkin 1970) noted that for Sardinops melanostica there was a strong correlation between dominance of phytoplankton or zooplankton in fish stomachs and their dominance in the plankton. Similarly, Leong and O'Connell (1969) concluded that it was important to determine the abundance and patchiness of the plankton of the southern Californian Bight to understand the feeding behaviour of the northern anchovy (E. mordax). They reported that E. mordax could not obtain all its energy requirements by filter feeding alone because average plankton concentrations were too low. Particulate feeding is necessary to fulfil its needs. This may also be true of E.capensis off the

Southwestern Cape where plankton concentrations are generally low but seasonally abundant (Brown pers comm.) whereas off Namibia plankton concentrations are much higher year round. Koslow (1981) reported that northern anchovy E.mordax feed selectively as a function of prey size unrelated to taxonomy and are not significantly affected by prey density. However, Loukashkin (1970) concluded that northern anchovy are mainly non-selective, omnivorous filter-feeders but that they can feed selectively depending on size and abundance of available food. In contradiction to this, he also noted an apparent preference for zooplankton. Engraulis japonicus has been reported as being mainly zooplanktophagous as juveniles and phytophagous as adults with a concommitant increase in gut-length compared to body length (Yamashita 1957). This agrees with the conclusions of King and Macleod (1976) who, in reviewing their data with that of other authors on various anchovy species, concluded that anchovy are zoophagous. Jones and Henderson (1987) presented a model for opportunistic feeding by omnivores as presented in Figure 50. If phytoplankton is vastly abundant - as is the case off Namibia - then the omnivore selects mainly for phytoplankton but if phytoplankton is fairly scarce (e.g. seasonally) and zooplankton become relatively more abundant the omnivore can switch to the higher, alternative, prey items. The reverse trend maybe true in other areas as conditions vary. Angelescu (1982) found a circadian variation in feeding behaviour of Engraulis anchoita. He described shoals of anchovy rising and disaggregating into surface layers from dusk till midnight when

intensive mixed feeding occurred. This was followed by descent and aggregation into shoals in the demersal layers accompanied by reduced feeding activity, mainly by filtering. Shoaling behaviour off Namibia and the southern Cape is the same (Cruickshank 1983b). Kruger and Cruickshank (1982) found stomach weights and fullness significantly higher at sunset than at dawn or early morning. They thus concluded that anchovy feed more in the late afternoon and evening than after midnight or in the morning.

Selectivity dependent on size and abundance of prey is crucial to whether the various species of anchovy are either phytoplanktivores, zoophagous carnivores, or omnivorous and whether they are mainly filter or particulate feeders. There are differences in the distribution and densities of phytoplankton and zooplankton in the different regions of the globe where anchovy occur. De Mendiola (1971) reported different dominances of phytoplankton and zooplankton in stomachs of the Peruvian anchovetta (E.ringens) off Peru and Chile which is related to the higher phytoplankton densities off Peru. Differences exist between the southern Californian Bight (Leong and O'Connell 1969) and Namibian waters (Kollmer 1963, Kruger 1983, and Kruger and Boyd 1984) and also between the Namibian coast and the Agulhas Bank off the southern Cape (Hutchings and Brown pers comms.). In all four of these regions there are major spawning stocks of anchovy. The northern anchovy of California and the Cape anchovy on the Agulhas Bank are possibly faced with a similar availability of food items.

Phytoplankton densities are low or unpredictably available (Brown and Hutchings 1985), hence a selectivity for zooplankton, as reported by Leong and O'Connell (1969), Loukashkin (1970) and James (1987), may be necessary for the fish to meet their energy needs. Off Namibia there is a very high density of phytoplankton along most of the coast and extending up to 45 n.miles offshore in some parts (Kruger 1983). This condition is prevalent year round but does increase seasonally (Kruger pers comm.) Anchovy shoals off Namibia are found in association with regions of high phytoplankton density (Cruickshank 1983a and this study). King and Macleod (1976) and Cruickshank (this study) have respectively shown the predominance of long, chain-forming species of diatoms in the diet of the Namibian anchovy by both night and day. Cushing (1978) suggests that large diatoms are automatically collected by the gill-rakers during feeding on zooplankton. Therefore, in high densities of phytoplankton, as in upwelling areas, large amounts of phytoplankton will be incidentally swallowed by the normal gaping action and irrigation of the gills. This is a valid argument but it fails in relation to the Namibian anchovy stocks because: It does not explain 1) the high percentage of phytoplankton and insignificant zooplankton portion reported by Davies (1957), King and Macleod (1976) and Cruickshank (this study); 2) the selectivity for some diatom spp. over and above their proportion in the water (eg. Nitzschia spp.); 3) If truly zoophagous, then anchovy off Namibia would be a predominantly offshore species like the pilchard is off Namibia and the anchovy over the Agulhas Bank in

the southern Cape.

STOMACH CONTENTS ANALYSIS

Analysis of stomach contents (Tables 3-16) were confirmed by the commercial catch samplings (Table 19) which showed that zooplankton did form an inconsistant but small part of the diet of anchovy larger than 8.0 cms. This agrees with previous studies of anchovy diet by King (1973b); King and Macleod (1976); Kruger and Cruickshank (1982) and is consistent with poor availability of zooplankton in some years, eg 1982 and 1984 (Kruger 1983 and pers comm; Boyd et al 1985).

Similarly, King and Macleod (1976) plotted phyto- and zooplankton species found in anchovy stomachs against their availability in the environment. Their study phytoplankton showed a trend in the guts closely following the availability in the environment although Rhizosolenia setigera was marginally favoured. In their analysis, zooplankton, although proportional to supply, showed a generally lower frequency in stomach contents than the availability, except 2 or 3 species which were favoured.

In the present study, the diets were dominated by five species of long, chain-forming diatoms, in particular Delphineis karstenii, Chaetoceros spp. and Rhizosolenia spp.. These were ingested in rough proportion to their availabiity but Rhizosolenia setigera was sometimes favoured despite low availability in the water

(Tables 3-13) and sometimes ignored (Figure 49). Protozoans, dinoflagellates and blue-green algae were apparently incidental (Figures 46-49). Delphineis karstenii and Chaetoceros spp. have long setae and, typical of diatoms, are covered in a gelatinous layer. Such features enable these species to stick to and wind round each other forming larger food parcels and patches readily available to feeding anchovy (Kruger, pers.comm.). This may be an important reason for their dominance in anchovy stomachs off Namibia. It suggests that selectivity is a function of size not taxonomy, and favours larger prey sizes as concluded by Koslow (1981). James (1984 & 1987) argues that the conclusions of King and Macleod (1976) and Davies (1957) are biased (1) because they only used samples collected at night and (2) because they did not present ratios of bulk. However, the present study addressed these problems but still confirms the hypotheses of King and Macleod. Samples were collected in the day and night and the stomach contents, volumes and weights were measured but remains of zooplankton formed such an insignificant fraction that it was not practical to measure them separately from the rest of the gut contents. Furthermore, in regard to the diet of anchovy off Namibia, James' (1984 & 1987) arguments fall down as follows:1) He ignores the vast differences between the systems, particularly the phytoplankton availability off Namibia compared to that off the western and southern Cape coasts. The differences are so pronounced that it is likely that his results would have been as different as he obtained from those of King and Macleod (1976) even had he

used the same methods. 2) He compares the South and West coasts of the Cape and, by implication and rejection of King and Macleod's (1976) work, presents this as representative of the whole range of E. capensis. 3) He proposes gut eversion in the net as explaining any absence of zooplankton but does not explain how the fish could still retain their guts fully distended with phytoplankton. James(1984 &1987) also rejects the possibility of prey-switching off Namibia as proposed by King and Macleod (1976) but states (James 1987) that anchovy do switch to phytophagy for survival during phytoplankton blooms off the Cape West Coast. This not only supports King and Macleod(1976) but is in agreement with the model for opportunistic, omnivorous feeding presented by Jones and Henderson (1987).

The good correlation between stomach contents of anchovy and the availability of the dominant diatom species in the environment supports the view that Engraulis capensis is an opportunistic feeder. From the literature on various species of anchovy from other parts of the world and from the studies on E. capensis by Visser et al (1973); Wessels et al (1974); King and Macleod (1976); Kruger and Cruickshank (1982) and James (1984 & 1987) and this study it seems that the Engraulidae generally are opportunistic and omnivorous feeders capable of both particle and filter-feeding with some selectivity towards larger-sized food items. There is a predominance of phyto- or zooplankton according to local availability which might be slightly affected seasonally or inter-

annually. In areas such as the Namibian coast where there is high density of phytoplankton the larger phytoplankton species are favoured. It is important to investigate whether it is advantageous in terms of net energy gain to feed on phytoplankton compared to the energy budget of a diet of zooplankton in the Cape system or whether as suggested by Dill (1983), different emphases in the diet may be a response to competition for the food resource. Competition is most likely from the other major clupeioid species in the region, the pilchard (Sardinops ocellatus), which is found further offshore (Cruickshank 1983a & b) in waters with abundant zooplankton. Other competitors are probably the horse mackerel (Trachurus capensis), the myctophid lanternfish (Lampanyctodes hectoris) and the bearded goby (Sufflogobius bibarbatus).

Davies (1957) concluded that the diet of the pilchard (Sardinops occellatus) in the St Helena Bay region might include seasonal ingestion of zooplankton. Davies also suggested that zooplankton might be more readily broken down and digested and therefore less easily detected or identified in the stomachs compared to the silica-protected diatoms. James (1987) claims that zooplankton are more easily digested by fish and may provide a better energy supply than phytoplankton. But, he ignores Seiderer et al (1986) who showed that anchovy guts are equally capable of digesting chitin-protected zooplankton and silica-protected diatoms. To substantiate James'(1987) view it would be necessary

to demonstrate that zooplankton digestion products are absorbed extremely rapidly and at a lot faster rate than phytoplankton when taken in together and that the phytoplankton is later voided. It is also not enough to rest argument as to the diet of anchovy on the fact that zooplankton have a better energy content than phytoplankton when zooplankton are so patently absent from the gut contents off Namibia. This was true for fresh specimens examined directly out of the water at all hours of the clock as well as specimens sampled when landed at Walvis Bay and was evident in the King and Macleod (1976) study also off Namibia. Such argument suggests rather that anchovy off Namibia may be under stress from competitors and/or insufficient suitable zooplankton to opt for the less energetically valuable phytoplankton diet. This could require more time (and effort) feeding and might explain the apparent lack of a clear distinction between night time feeding and daytime digestion/inactive periods off Namibia as described herein (p127) and by Krüger and Cruickshank (1982).

The results indicate that the conclusion of King and Macleod (1976) that anchovy become entirely phytophagous as adults after particulate feeding on zooplankton in the larval and juvenile stages requires modification. King and Macleod (1976) concluded that the transition phase, if it is that, occurs at about 8.0cm due to gill-raker development. However, this study shows that zoophagy can persist a lot longer. James (1987) has shown that off

the Cape zoophagy predominates in the diet of anchovy of all ages with opportunistic switches to phytoplankton in bloom situations.

It will be necessary to make an extensive survey of the distribution and diet of the pre-recruit juveniles (3.5-6.5 cms) plus recruits and adults in cooperation with an accurate, quantitative study of phytoplankton and zooplankton availability off Namibia to fully determine their feeding ecology and behaviour. In this way a better understanding of the survival of juvenile anchovy to the stage of recruitment into the fishery will be obtained.

Feeding patterns and intensities

The Namibian anchovy population peaked in 1978-1981 during which shoals were detected widespread and further offshore than was the case in the subsequent decline that lasted until the very strong recruit year class in 1987. As the population shrank from 1980 onwards so shoal distribution (as determined by commercial fishing activities) was confined to areas of prime food availability, viz. dense phytoplankton regions nearshore, as described by Kruger (1983) and Cruickshank (1983a) for 1979-1982. Thomas and Boyd (1985) and Fearon et al (1986) described the collapse in the anchovy recruitment following marked changes in temperature regimes as well as plankton composition and density due to an El Nino warm event in 1984.

Feeding data for 1980-1985 extracted from Sea Fisheries

commercial catch samplings for Namibia indicate that there are two important feeding areas for juvenile and adult anchovy in between 19° and 20°S and between 22° and 24°S (Table 20). These feeding areas are dominated by phytoplankton and may influence the migration patterns of anchovy off Namibia. The frequency of stomach fullness showed a trend of increase from the south (between Hollams Bird Island and Luderitz) to further north (between Conception Bay and Cape Cross) in progression from summer and autumn to winter. There was also a concommitant increase of feeding in the areas north of Palgrave Point (Table 20). It is also likely that the prime feeding grounds influence the choice of spawning areas.

The proportion of zooplankton in anchovy diets off Namibia might reflect an autumn and late winter seasonal switch in selectivity in towards zooplankton or a weak inter-annual variation in years of greater zooplankton availability over phytoplankton. But it may also reflect differences in the diet of adults and juveniles. Adults are caught in early winter close to the coast in dense phytoplankton mainly north of Palgrave Point (King 1973; Ratte 1973; Cruickshank 1983a & this study) whereas juveniles and immatures dominate the catches in late winter and are found in the south and central areas more offshore where there is a mixture of phytoplankton and zooplankton available.

The size of the anchovy stock off Namibia is probably determined by a balance between several mechanisms. This study has highlighted

the diet and feeding patterns of anchovy and possible influences of: the temperature and current regimes; phyto- and zooplankton availability associated with upwelling; the loss or survival of larvae due to offshore drift; migration by different components of the stock, which benefits abundance according to Nikolsky (1963, quoted in Harden-Jones 1968). There are other factors affecting the stock size of anchovies such as excessive predation pressure exerted by the commercial fishery; the effects of turbulence in the surface waters on feeding; competitive interactions with other epi- and meso-pelagic species; reproductive strategies; population density effects and biological predation but it is beyond the scope of this thesis to discuss all the relevant theories.

In conclusion then, it can be stated that available evidence suggests that anchovy are omnivorous, mainly particulate feeders selecting long, chain-forming diatoms in regions of high phytoplankton densities but also feeding, sometimes extensively, on local concentrations of zooplankton when available. This scenario is typified off Namibia but in the south western Cape waters, particularly over the Aghulhas Bank region, where the phytoplankton densities are low for most of the year (Brown pers comm.) anchovy diet has been shown to be dominated by zooplankton (James 1987). Information in the literature on anchovy species in other parts of the world also reflect this contrast in selectivity. It seems reasonable then, to accept that the model of omnivore feeding

strategy proposed by Jones and Henderson (1987) is in operation. It is a strategy suited to enable the anchovy to remain flexible to meet its daily feeding requirements within the complex environmental systems off our coasts. It enables the anchovy to complete its life cycle and, by means of a migration cycle, which is regulated by ocean current regimes as well as by feeding and spawning needs, may also avoid intra-specific competition with its own offspring.

SECTION D : CONCLUSION

1. REVIEW OF CONCLUSIONS

Notwithstanding clearly understood difficulties and limitations of the techniques and available results, this study provides analysis and interpretation of extensive survey work and related commercial fishing data. Inter-annually there is a consistant pattern of distribution of anchovy shoals off Namibia. Within the range from the Cunene River (17°S) to just south of Luderitz (26°40'S) distinctive components of the anchovy stock can be distinguished. After comparing the results with existing knowledge in the literature the following conclusions are set out:

1. Adult shoals occupy feeding grounds north of Palgrave Point in winter. These shoals migrate in summer to the major spawning grounds north of Rocky Point (19°S), west of Dune Point (20°S) and between Walvis Bay and Hollams Bird Island. Spawning products drift passively offshore due to Ekmann transport and are presumed to come under the influence of stronger current movements such as intrusions of the Angolan Current which can reach south of Walvis Bay (Visser et al 1973; O'Toole 1977; Boyd et al 1987). The southward movement of eggs and larvae from the spawning areas to the southern nursery remains a major gap in our understanding of the migration cycles. So far such movements have not

been recorded.

2. Post-larvae and juveniles occur further south in an apparent nursery area towards Lüderitz where there is abundant food.
3. The growing juveniles migrate northward and accumulate during winter on "recruit" feeding grounds off Walvis Bay where they grow rapidly and become available to the fishery.
4. This migration continues northward and reaches the northern (adult) feeding grounds in late winter and spring when they apparently "disappear" from the Walvis Bay region.
5. South of the well-known "environmental barrier" around Lüderitz there is a consistant but variable stock of juveniles and recruits between Chamais Bay and Hondeklip Bay. Length frequency data and acoustic surveys along with data on larval drift indicate that this is not a truly Namibian stock but a component of the South-western Cape stock.
6. Anchovy distribution is shown to coincide with environmental features, notably temperature and plankton (mainly phytoplankton) but the important influence of forcing mechanisms such as ocean currents, upwelling and associated eddies are stressed.
7. Studies of the feeding ecology of anchovy based on field sampling plus data from routine sampling of the commercial landings at Walvis Bay show that phytoplankton dominate the diet of adult and recruit anchovy off Namibia. Different species of large, chain-forming diatoms are represented in proportion to their availability.
8. Sporadic dominance of zooplankton in the diet on a weakly seasonal

and an inter-annual basis suggests that anchovy are opportunistic omnivores, selecting according to the abundance of supply. Size seems to be important because larger prey items predominate in the diet while smaller items are excluded. An in-depth study in Cape waters (James 1987) reached the same conclusion but found the dominant component there to be zooplankton with sporadic ingestion of larger phytoplankton.

9. The difference in dominance of phyto- and zooplankton in the diet of anchovy off Namibia compared to that off the Cape's south and west coasts is in keeping with an animal occurring in two distinctly different regions, the one dominated by phytoplankton year-round, the other dominated by zooplankton with sporadic phytoplankton blooms associated mainly with upwelling pulses in summer. These reported differences in diet thus fulfil the conditions of flexibility in diet set out by Dill (1983) and Jones and Henderson (1987) for omnivorous, opportunistic feeding characteristic of anchovy.

10. Using stomach fullness from commercial catch samples as an index, there are two, clearly distinct, major feeding areas within the anchovy distribution off Namibia. The most important is between 22°S and 24°S. This is in an area dominated by recruit fish in winter. A second important area between 20°S and 21°S is dominated by adult fish. These represent adult and recruit winter-feeding grounds - an important concept in considering migration patterns. The juveniles found off Namibia tend to be further offshore where zooplankton is abundant along with phytoplankton while the adults

feed in inshore zones where phytoplankton is dominant.

11. The components of the anchovy stock summarised in Figure 43 together with the major current systems of the region summarised in Figure 42 show that the movements of anchovy in Namibia are more complex and less clear-cut than the picture that has been developed for the South African stocks. The situation off Namibia therefore requires further, intensive investigation.

2. PROPOSED FURTHER RESEARCH

Though many of the arguments put forward may be tenuous or controversial, only further information can test the views expressed herein. Therefore, to resolve some of the questions raised and to improve our knowledge of the migrations of anchovy recruits off Namibia, the following further research is suggested:

a) It is urgently necessary to undertake dedicated surveys of the distribution of anchovy post-larvae and early juveniles from north of the egg and larval concentrations around Cape Frio to the southern end of the proposed nursery grounds (about Lüderitz). The survey should use gear with an opening/closing mechanism such as RMT-type nets sampling to 100m depths and, where possible, up to 100 n.miles offshore not just to 50m and 65 miles as is traditional off Namibia. Such a survey should be conducted in the late summer and autumn when post-larvae and early juveniles should be at a maximum after the peak spawning season of January - February.

b) Short, follow-up cruises in early and mid-winter should survey selected parts of the distribution to trace the paths of the juveniles on the nursery grounds.

Both (a) and (b) should be repeated for at least two successive years but it is important to maintain a continuous, long time-series.

c) Equally important is an investigation of the current regimes off Namibia. In particular, it is necessary to define the extent, depth and rate of the Angolan Current intrusions from the north and to confirm or deny the presence of an offshore southward counter-current between Cape Cross and Lüderitz, as described by Yelisarov (1967), and the effect of the eddy currents offshore south of Walvis Bay described by Lutjeharms and Stockton(1987).

d) It is important to survey shoal distribution off Namibia regularly each year. But it is essential that the data be quantified to get realistic information on the proportions of the early juvenile and recruit components as well as adults, along with their respective distributions.

e) An in-depth study of anchovy diet compared to age and environment must be completed off Namibia. For this, stomach contents should be sampled for every 2° of latitude between 17°S and 27°S. Simultaneously, accurate and quantitative sampling of phytoplankton, macro- and microzooplankton must be carried out. Analysis of stomach samples should identify proportions of the food items by volume and weight cf. fish weight, as well as detailed identification and enumeration of frequency. Phyto- and

zooplankton fractions in the guts and the environment should be analysed for proportional energy values cf. mass.

f) An in-depth study of the plankton communities off Namibia relative to the major oceanographic influences is needed. This should provide core data on the links between hydrology, plankton and pelagic fish. The sampling procedures and nets used off Namibia (Kruger 1983, Kruger and Boyd 1984, LeClus and Kruger 1982) have provided a valuable time series of data but were inadequate for quantitative data on the vertical and horizontal distributions of zooplankton in particular. This is a serious shortcoming which ought to be addressed in future studies off Namibia.

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APPENDIX - LIST OF FIGURES

Figure 48 STRAIGHT LINE REGRESSION BETWEEN ORGANISMS IN THE GUT CONTENTS AND THE ENVIRONMENT, AUGUST 1981
Regression including all data points produced a graph (dotted line) with a weak correlation co-efficient and low confidence value. A second regression, excluding organisms infrequent (<30%) in the gut content, Nitzschia spp. (highly favoured) and "other diatoms" (irrelevant), produced a graph (solid line) closely fitting a 50:50 ratio of frequency in stomachs and water samples. The correlation co-efficient was good with a high confidence value.

Figure 49 STRAIGHT LINE REGRESSION BETWEEN ORGANISMS IN THE GUT CONTENTS AND THE ENVIRONMENT, MARCH 1982
Regression including all data points produced a graph (dotted line) with a weak correlation co-efficient and low confidence value. A second regression, excluding organisms infrequent (<30%) in the gut content, Nitzschia spp. (highly favoured) and "other diatoms" (irrelevant), produced a graph (solid line) closely fitting a 50:50 ratio of frequency in stomachs and water samples. The correlation co-efficient was good with a high confidence value.

Figure 50 MODEL OF OMNIVORE FEEDING RELATIVE TO PREY ABUNDANCE (from Jones and Henderson 1987)

APPENDIX: PAPERS SUPPORTING THIS THESIS

ICSEAF 1983 (Part II)
Collin scient. Pap. int. Comm SE. Atl. Fish.
Pages 75-97

DISTRIBUTION OF PELAGIC FISH SHOALS DETERMINED BY ACOUSTIC SURVEYS IN 1981-1982 AND ITS RELATIONSHIP TO ENVIRONMENTAL FACTORS

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INTRODUCTION

Regular hydroacoustic surveys have been conducted in ICSEAF Divisions 1.3-1.6 every summer and autumn since 1978. This report deals with survey material from Divisions 1.3 and 1.4 for 1980/81 and 1981/82, as the surveys have concentrated primarily on these two divisions. The results of the past two seasons reflect the current situation in the fishery and are the most pertinent to current management.

Workers in other parts of the world, e.g., Johannesen and Losse (1977) and Hampton (in press) have surveyed marine stocks using echo-integrators coupled to a scientific echo sounder. Hewett et al. (1976) have also done surveys using a bounced sonar beam mapping technique. Cram and Agenbag (Sea Fisheries Research Institute, unpublished manuscript) used acoustic surveys and a catcher vessel to provide backup for aerial surveys off the South West Africa/ Namibian coast. The work reported on in the present paper has relied on direct surveys using simple hydroacoustic techniques supported by target-directed purse seine fishing. Ancillary data from the SWAPELS sampling has also been used, and in February and March 1982 the surveys were combined with an aerial survey of the northern fishing grounds (ICSEAF Division 1.3).

The results have been analyzed in terms of environmental factors and compared to commercial pelagic fishing patterns during the winter months.

Notwithstanding problems pointed out by Cram and Hampton (1976) and Squire (1978), these hydroacoustic pelagic fish surveys off South West Africa have provided sufficient reliable data on shoal distribution to permit a consideration of its relationship with ecological factors as well as to support conclusions derived from other surveys conducted during the same time period. The results obtained in the past two years have been extremely useful.

This report deals only with the findings of the 1981 and 1982 summer surveys and winter commercial catches. Discussion will centre on shoal movement patterns and relevant hydrological and plankton data. More detailed studies including winter surveys of shoal behaviour akin to the hydrology will be published separately (Cruickshank, unpublished manuscript).

METHODS

ICSEAF Divisions 1.3 and 1.4 were surveyed in November/December 1980 and from January to March/April 1981 as well as in November/December 1981 and January to March 1982.

The sonar and 120 kHz scientific echo sounder on the Sea Fisheries Research Institute's research ship "BENGUELA" (in 1981) and R.S. "SARDINOPS" (in 1982) were used in surveys completed in conjunction with the SWAPEL surveys. From January 1981 a parallel but more intensive survey was carried out in concurrent weeks each month using a chartered purse seine vessel. This vessel was also equipped with a sonar and 120 kHz echo sounder and, being a commercial fishing boat, it could identify and sample selected targets within the upper $\pm$ 50 m or 20 fathoms.

The grid extended from just south of the Cunene River to Spencer Bay (25°30' S). The capture vessel's main function was initially not to survey but to sample and identify targets selected from the R.S. "BENGUELA". From January 1981 the survey strategy was modified. The purse seiner's function became survey and target identification, while the research vessel provided survey data from more sophisticated equipment. Targets were selected by the scientist in charge from the capture vessel, which was released to operated more or less independently of the R.S. "BENGUELA". Thus, the "BENGUELA" kept to the 65-mile-per-line SWAPELS grid, while the purse seiner operated between the coast and 45 nautical miles, covering the coastal waters more intensively with grid lines spaced only 10 miles apart. The purse seiner was not chartered in November/ December 1981, because past experience has taught that at that time of year, during spawning activities, the pelagic species (except horse mackerel) are not detected in sufficient frequencies to be of value compared to the high survey costs. The activity of predators, such as gannets, which might indicate the presence of fish was also

noted when appropriate. Frequency of target detection (= fish availability) generally improved in the summer months from January to April each year off South West Africa. Target shoals captured were not loaded; instead, up to one tonne (usually only half a tonne) was pumped aboard and the shoal released. All species present were identified and their proportions in the catch estimated or calculated from a random bucket sample which was separated and counted according to species. The latter was only possible if sufficient numbers of each species were present in the sample. When this was not the case, an estimate was made. A random sample of ± 200 fish of each species was taken (semi-selected in the case of species present in smaller numbers), and the samples were frozen and taken back to Walvis Bay, where regular bulk sample and subsample analyses were performed.

Acoustic data were then analyzed and identified according to the sample data, egg and larval data, and any other biological information obtained from bongo net sampling and visual identification of species from the vessel or, subsequently, from an aircraft. The distribution of shoals was plotted in ten-mile grid squares on a coastal map of South West Africa (Figures 1-9). These charts were then compared to plankton and oceanographic charts for the same survey periods, and any significant trends were noted.

Winter commercial catch data for the subsequent fishing seasons were analyzed in terms of catch totals per half degree of latitude (10-mile grid squares were not available at the time of publication) plus depth sounding contours, and they were plotted on the same grid maps as the summer surveys. Comparison was again made with the oceanographic environment (Figures 10-12).

Thus, the summer, autumn, and winter pelagic fish shoal distributions were set out in sequence and then related to their environment, and finally comparative trends were noted.

RESULTS

The overall pattern emerging from the 1981/82 summer hydroacoustic survey off South West Africa is described below.

There was little or no sign of adult anchovy (or other species) south of Walvis Bay, nor was any sizable juvenile recruitment evident.

North of Cape Cross patchy distribution of small shoal groups apparently shifted northwards past Palgrave Point as autumn progressed. These shoals linked up with the large but very thinly spread shoal group from Palgrave Point to Möwe Bay. The main concentration of this extensive shoal group was centered off Terrace Bay, where it was found in large blocks close inshore in fairly shallow water. The rest consisted of many small shoals, averaging perhaps ten tonnes (1-20 tonnes), in a coastal belt inside five miles but sometimes up to 15 miles offshore. On the basis of shoal frequency within the group, shoal size and sample catches, this shoal group consisted of approximately 25 000 tonnes.

From Black Sand Castle to Cape Frío another widespread shoal group was detected up to 25 miles offshore, but it moved eastward to within ten miles from shore in March. The greatest concentration was southwest of False Cape Frío but at best consisted of medium-size targets. No large shoals or blocks of fish (as at Terrace Bay) were found in this group. Shoal sizes mostly ranged between one and ten tonnes, with an estimated total of 10 000 tonnes for the whole group. The entire anchovy stock north of Toscannini was estimated to not exceed 50 000 tonnes. Average fish length was considered to be 9-10,0 cm (L_c), and allowance was made for 30 % at only 7,5 cm average length likely to represent greater fish weight in the winter than at the time of survey. These estimates included a number of variables and should be treated with caution. However, allowing for some variance due to shoals for which positive species identification could not be made and for increased tonnage with maturity, it compared fairly closely with the actual tonnages (83 760 tonnes) realized by the fishery during the winter.

Regardless of the length class, all fish handled were in excellent, fat condition in all months sampled. Gonad stages indicated that peak spawning was completed in February. The ratio of females with spent gonads increased from 20 % in January to 50 % in February and 80 % in March. This concurs with the egg concentrations found in the SWAPELS samples, which were higher in February (Le Clus 1983).

Sampling of horse mackerel was inadequate to obtain a distinct picture of their shoal movements on the basis of the positive identifications made. However, considering the known groups and the areas where mixed and unidentified shoal groups were detected (Figures 1-9), a trend can be seen. The shoal groups were generally found between 5 and 15 miles offshore, with a shoreward shift in density (i.e., between 5 and 15 miles).

In January three shoal groups were evident, viz., between Cape Frío and Rocky Point, between Black Sand Castle and Dune Point (offshore), and from Dune Point (nearer shore) to Toscannini. Only two, almost continuous, big shoal groups were positively identified in February, from Cape Frío to Black Sand Castle and from Möwe Bay to Torra Bay. By March these shoals were found to have split into a group north of Rocky Point and a small, dense group west of the Sand Tables, with another large but mixed species group between Torra Bay and Toscannini. This stock was estimated to be likely to yield about 25 000 tonnes. Much more than this (66 973 tonnes) was taken in the winter fishery. Underestimation is most likely due to insufficient species sampling from possible targets.

A large group of pilchard shoals present in dense 10-20 fathom targets was present between Möwe Bay and Sand Table Hill in January and February. Initially this group was found between 25 and 35 miles offshore, but by February it had moved east to between 10 and 20 miles from the coast. A large group of trawlers was busy on this fishing ground. In March there was no trace of the shoal group other than a minor stranding at Möwe Bay seen from onshore by the aerial survey team. Based on January data, this group is estimated to have constituted between 40 000 and 75 000 tonnes. In February it was still estimated at 50 000 tonnes.

Insufficient samples, particularly in February, preclude any definite estimate in connection with the three shoal groups detected south of Palgrave Point. However, it is consid-

ered doubtful that these shoals totalled more than 12 000 tonnes. This estimate is borne out by the catch levels of commercial purse seiners in March from Durissa Bay to Toscannini and west of Cape Cross and Henties Bay.

Consequently, the gross estimate of the stock before the beginning of the 1982 pilchard season in March was reckoned to have been between 60 000 and 75 000 tonnes. The fishery took 51 370 tonnes. All fish handled from the samples were in excellent, fat condition, and a large proportion had ripe gonads even in March, although peak spawning occurred in February, with a marked drop-off in March (Le Clus 1983).

Juvenile size ranges according to distribution

In January the anchovies caught between Rocky Point and Terrace Bay ranged from 9,5 to 12 cm (mean: 10 cm) in length, whereas in March the range between Sand Table Hill and Dune Point was 7-12 cm (mean: 8,5 cm) and off Walvis Bay 11-13 cm. Clearly, then, there was a supplement of new recruits to the north in late summer.

Horse mackerel catches showed a similar trend, with juveniles ranging from 6,0 to 16 cm in the north and 5,5 to 10 cm in the south in January. This changed to ranges of 9,0-17,5 cm in the north and 10,0-13,0 cm in the south. Catches in the south suggest a late summer movement of juveniles from the Conception Bay area (5,5-10 cm) in January to the Sandwich Harbour region (7,0-12,5 cm) in February and finally to between Walvis Bay and Swakopmund (10,0-13,0 cm) in March. Pilchard lengths ranged between 12,0 and 20,0 cm in January, 15,0 and 20,5 cm in February, and from 9,5 to 23,0 cm in March.

The 1980/81 summer acoustic survey very clearly showed the southward movement of post-larval and juvenile anchovy in late summer, followed by an autumn return of older juveniles reaching past Walvis Bay to just south of Henties Bay in April and May. Evidence of this was a consistent layer of small, scratch-like shoal targets in the acoustic records between 15 and 25 nautical miles offshore from Pelican Point to 26° S, just north of Ichaboe Island. Sampling of this layer at various positions repeated from January to March produced a series of post-larval and juvenile fish ranging in size southward from 2 to 7 cm in February and March, with a "folded-back" progression from Ichaboe Island to Hollams Bird Island of 6-8,5 cm; these small juveniles were encountered again off Pelican Point. This was confirmed by the commercial fishery in April and May.

Length frequencies from the commercial fishery were not available by latitude at the time of publication and are not discussed here.

Summer distribution relative to sounding and distance offshore

During the summer survey anchovy were found concentrated almost exclusively within the 50-fathom contour. The main concentrations were further confined within 2-7 miles offshore, i.e., in less than 20 fathoms. Pilchard were initially found at midshelf over the steep fall-off to 100+ fathoms. The shoals shifted slowly shoreward each month as autumn approached but still remained concentrated beyond 50 fathoms. Horse mackerel showed no consistent trend, although they were generally found at 30-50 fathoms depth, sometimes forming a cordon between the anchovy and pilchard shoal groups. The pilchard shoals remained separate from the other species, while the horse mackerel and anchovy shoals were freely intermingled at night, forming larger, independent groups of shoals in midwater during the day.

Aerial surveys conducted from Möwe Bay by the Sea Fisheries Research Institute in corresponding periods of February and March found similar distribution patterns and also discerned a shoreward movement of shoals from February to March without finding any obvious relationship with the environmental data that may have influenced this shift (Agenbag et al., Sea Fisheries Research Institute, unpublished manuscript).

Commercial catch data

Full details of the commercial fishery statistics are given in Le Clus and Melo (1983), and therefore the data will not be repeated here. Instead the reader is referred to Figures 13-21 herein and the relevant tables given in Le Clus and Melo (1983). Only aspects relevant to the ecology and comparison with the summer survey data are discussed in this report.

Alongshore distribution

Considering the graph of alongshore distribution for winter commercial catches (Figure 15), horse mackerel show little change in 1982 from 1981 except in volume, since catches were good in 1982, particularly between 19° S and 20°30' S.

Anchovy distribution (Figures 10 and 13) shows the same three area peaks at 18°30'-19°30' S, 20°30'-21°30' S, and 22°30'-24° S. However, the usual major peak south of Walvis Bay was seven times smaller in 1982 than it was in 1981 and shifted 1° of latitude north, to 22°30' S. This difference will be discussed further on. An average length (L_c) of 8,8 cm per fish indicates that the late peak in August mainly in the south was composed of juvenile recruits, which does not imply any detrimental effect on their growth since February due to the colder-than-usual temperatures in the autumn and winter of 1982. The central area peak is smaller by 8 000 tonnes and is deflected slightly south, while in the north the third peak is 6 000-10 000 tonnes higher and deflected slightly north. These shifts may have resulted from three features. Firstly, there were the colder-than-usual temperatures mentioned above by Boyd (1983). Secondly, the very low phytoplankton available south of Palgrave Point, as can be seen from Figures 5, 6, and 7 in Kruger (1983), meant that there was little food available in the south. Thirdly, if there was a marked failure in larval survival in the north, there would have been lower-than-normal population pressure to force juveniles to move south and past Cape Cross.

Peak pilchard catches in 1982 were markedly further north than in 1981. Whereas the 1981 peak was west of Henties Bay at 22°30' S, all catches in 1982 were north of 21°30' S, with the major peak at 19° S in ICSEAF Division 1.3. The 1981 peak of age 1+ pilchard off Henties Bay has already been discussed by Le Clus and Kruger (1982). The 1982 peak in the north was made up of low catches caught consistently each month

in Division 1.3, with a peak in September. While catches were made as far south of Pelgrave Point as 21°30 S (Cape Cross) in March and July, only 47 tonnes were caught west of Henties Bay, compared to 33 431 tonnes in 1981. No clear correlation for this feature is apparent. Numerical strength of the stock was probably reduced by insufficient recruits surviving from the previous seasons and reduced larval survival in February due to the sudden deterioration in the environment. Continued poor environmental conditions (low temperatures and poor phyto- and zooplankton productivity or availability) kept the shoals away from this usually abundant fishing ground.

DISCUSSION

Boyd (1983), Le Clus (1983), and Kruger (1983) have each explained aspects of the effects of environmental changes on larval survival in 1982. A few remarks on the trends observed in the behaviour of the shoals of juveniles and adults will be discussed here in relation to environmental features.

Kruger (1983) has shown the inshore predominance of phytoplankton and the offshore concentrations of zooplankton. The late summer phytoplankton distributions given fit the inshore, shallow-water distribution of anchovy found during the acoustic surveys. This is seen in January and March, when anchovy were found almost exclusively in phytoplankton-rich and zooplankton-poor waters, or where only phytoplankton were present. Pilchard, on the other hand, were found in waters where phytoplankton was poor or absent and zooplankton was richer. This is best observed in January and February, when the highest zooplankton concentrations closely overlapped with aggregations of pilchard shoals in the north and to the west of Cape Cross. Horse mackerel did not show a consistent pattern, in that they were associated with anchovy in the highest-density phytoplankton inshore from the zooplankton areas. In February and particularly March, horse mackerel distribution overlapped very exactly with the zooplankton concentrations. Southwest of Cape Frío in March, both zooplankton and phytoplankton were high, but phytoplankton predominated in areas where anchovy and horse mackerel shoals were found. King and MacLeod (1976) give proportions of feeding preferences for pilchard and anchovy as 85 % zooplankton and 15 % phytoplankton in juveniles, but in adults they found 80 % phytoplankton to 20 % zooplankton for pilchard and 71 % to 29 % for anchovy. The distribution patterns of the fish shoals according to phyto- and zooplankton availability do not show any evident direct correlation. Stomach contents observed in bulk samples over the last few years have shown a roughly 35 % preference overall for phytoplankton, particularly in anchovy (Sea Fisheries Research Institute, unpublished data). A further, detailed analysis of the feeding ratios is nearing completion and will be published in a separate report (Cruickshank, unpublished manuscript). However, the 1981 and 1982 acoustic surveys and commercial fishing indicate a preference by anchovy for areas of high phytoplankton volumes, while, in comparison, pilchard prefer a higher proportion of zooplankton. The anchovy's preference for high phytoplankton concentrations is assumed to be an additional factor inhibiting the influx of recruits to the waters south of Walvis Bay, where much lower-than-average phytoplankton levels were reported for February and March (Kruger 1983) and lower-than-average temperatures in the upper 20 m were reported by Boyd (1983).

Most shoals were detected in the upper 25 m in all three months. Noticeably, even horse mackerel did not form dense, cone-shaped shoals on or near the bottom, as is generally the case in the daytime. This may have been due to the strong thermoclines reducing the penetration of oxygen-rich water from the surface to below 20 m as reported by Boyd (1983). Horizontally, species distribution related to dissolved oxygen levels was not consistent for the areas south of Ambrose Bay (21° S).

Unfortunately, no oxygen data are available for the north. In January pilchard distribution followed the zones of high surface oxygen (>5,0 mℓ/ℓ), while anchovy occurred in waters with low surface oxygen (<5,0 mℓ/ℓ). Horse mackerel occurred in areas of low dissolved oxygen in the south during March, while both anchovy and pilchard were detected in areas of high surface oxygen values. Detailed studies of behaviour in relation to hydrology (Cruickshank, unpublished manuscript) suggest that dissolved oxygen itself does not seriously influence shoal distribution, except in the case of anoxic conditions or rapid depletion. Otherwise, its relationship with shoal distribution is probably associated with phytoplankton production.

No direct link was noted between shoal distributions and salinity, although the highest salinities were reported by Boyd (1983) north of Palgrave Point, where the greatest concentrations of fish by far were found. Shoals of all species occurred "above" the 35,4 ‰ isohaline generally, except in the south, where in January the few shoals detected were found between the 35,1 and 35 ‰ isohalines.

Temperatures in the upper 20 m compare differently for each species. Anchovy were not recorded in waters with temperature above 17 °C or below 13 °C and were mostly restricted to the 16 °C isoline. Pilchard were always "above" this limit and generally "above" 17 °C. The main pilchard concentrations were between 17 and 19 °C in January, between 18 and 20 °C in February, and between 18 and 19 °C in March. Horse mackerel occurred between 16 and 19 °C in all three months. Kruger and Cruickshank (1982) discussed the relationship between temperature and pelagic fish shoal distribution, but they found no significant effect attributable to temperature during their survey. Agenbag (1980) found pelagic shoals in winter confined to temperatures below 15 °C. This is not consistent with the findings reported here. It is likely that temperatures normally found off South West Africa/Namibia do not usually influence the adult fish per se, but sudden changes of temperature of 1 or 2 °C, as experienced in February 1982, may influence larval survival by affecting phytoplankton availability and the penetration of dissolved oxygen to deeper layers. Nitrate concentrations matched some portions of the shoal distribution but showed no definite correlation. Once again it is assumed that this factor has little direct influence on the shoals. Any correlation with pelagic fish is probably linked to phytoplankton production.

Commercial catch distribution according to depth sounding/distance offshore

As can be seen from the charts in Figures

1-9, the bottom depth contours of 10, 30, 50, 80, and 100 fathoms roughly correspond to distances of 5, 10, 20, 30, and 40 nautical miles offshore along most of the coastline except between 21°30' S and 23°30' S.

The season catch totals according to bottom depth sounding in 10-fathom stages are presented for each species in Figures 16-18. North/south differences in ICSEAF Divisions 1.3 and 1.4 are shown in Figures 19-21.

Pilchard catches show distributional differences between the north and south in 1982. A marked increase in tonnage was obtained further offshore in deep water in Division 1.4, whereas in Division 1.3 a peak was obtained between 20 and 30 fathoms, with a marked tapering-off further west in deep water. This is similar to the situation during 1981 in the north, while the south differed in that there was a peak between 40 and 50 fathoms, again tapering-off to the west.

The pattern for horse mackerel was generally the same, with a nearshore peak and sharp decline, then gradual tapering-off towards deep water in both the north and south. The 1982 winter season was different from the 1981 season only in the 15-20 times larger catch total in 1982 and the fact that the 1982 peak was between 20 and 30 fathoms, compared to its position in 10- to 20-fathom waters in 1981. The only explanation for this at present is the warmer water conditions nearshore in 1981 and the low food availability in autumn 1982.

There is little difference between the north and south distributions in 1982 except that the southern peak extends from 10 to 50 fathoms, whereas catches in the north were practically confined to the 10- to 30-fathom depth range. The same was true of the low catches in the north in 1981. In the south catches were generally high in waters less than 70 fathoms deep. The major peak was between 50 and 70 fathoms, with a sharp cutoff towards 100 fathoms. Probably less effort was spent fishing deeper waters because of ample fishing in shallower waters. Comparing the summer distribution of anchovy shoals to the pattern of commercial anchovy catches in winter, there is a clear trend of southward movement from the north, primarily among juvenile recruits. In other words, there is southward movement away from the nursery grounds in the far north, although there is insufficient evidence on which to propose a large-scale migration from the far north past Walvis Bay to the south. Rather, it is suggested that there is southward displacement from the peak spawning areas north of Möwe Bay in a chain sequence of lesser spawning peaks, with an accumulation of recruits in the south comprising the juveniles spawned between Walvis Bay and Meob Bay and a large supplement from the areas north of Cape Cross. The recruits from the southern spawning grounds also show southward movement as they mature, but once they reach 7 or 8 cm they turn about, roughly between Spencer Bay and Ichaboe Island, and move steadily northwards until they reach Sandwich Harbour and Walvis Bay. This is clearly discernible in the 1981 summer hydroacoustic survey results but was masked in 1982 by either delayed development or non-survival of juveniles and late recruitment to the fishery. If the juveniles from the south had moved further south than expected, past Ichaboe Island, they would not have been detected, because bad weather precluded penetration by the survey's vessel south of Easter Cliffs. However, the intensity of spawning in the Walvis Bay to Conception Bay area (Le Clus 1983) suggests that this is unlikely to have been the case without some trace of the earlier stages being detected. It is more likely that the unusually high density of chub mackerel and snoek had a detrimental effect in depleting the numbers of juvenile anchovy and scattering the remainder so much as to disrupt their ability to reform shoals. If the latter is true, the remaining anchovy juveniles could have been less efficient in their search for food, further reducing the numbers surviving to recruitment. This is confirmed by the stomach contents of chub mackerel and snoek, which contained juvenile anchovy and tiny hake (Merluccius capensis). Furthermore, on previous surveys chub mackerel have been observed in large shoals up to 60 miles west of the Orange River actively chasing shoals of juvenile anchovy (4,0-7,0 cm). Stomach contents of these chub mackerel and bongo-net tows confirmed the presence of young anchovy.

CONCLUSIONS

Stock estimates from hydroacoustic surveys did not indicate a very profitable season of anchovy fishing due to the small stock size, the great distance of shoals north of Walvis Bay, and a lack of notable juvenile recruitment from the area south of Walvis Bay. There was no evidence of a horse mackerel "disappearance" at the end of summer. The quantity of fish was stable during the survey period, despite changes in distribution; and, as predicted, the stock yielded much more than in 1981. The lack of very young fish during the survey was not a good sign for future recruitment. Findings by a concurrent aerial survey were similar to those of the 1982 survey, and trends in the fishery subsequent to these surveys have matched those predicted from the results. This indicates that simple acoustic surveys of this sort are of value in obtaining information on which to base predictions which may be useful in management and can be compared to other biological and hydrological information.

Oceanographic factors, particularly in the north, had a detrimental effect on all three major pelagic species at the end of the summer and during the winter. Direct stimulation of shoal movements by some otherwise important hydrological factors is discounted, and instead their indirect influence in the environmental web is suggested.

The ecological processes this year and the increasing importance of the far northern region to the fishery makes it essential that more ecological information be gathered from that region. Thus, more extensive and regular monitoring of the hydrology of ICSEAF Division 1.3 should be instituted to start building up a time series of data to back up other investigations into pelagic fish biology and behaviour in that region.

ACKNOWLEDGEMENTS

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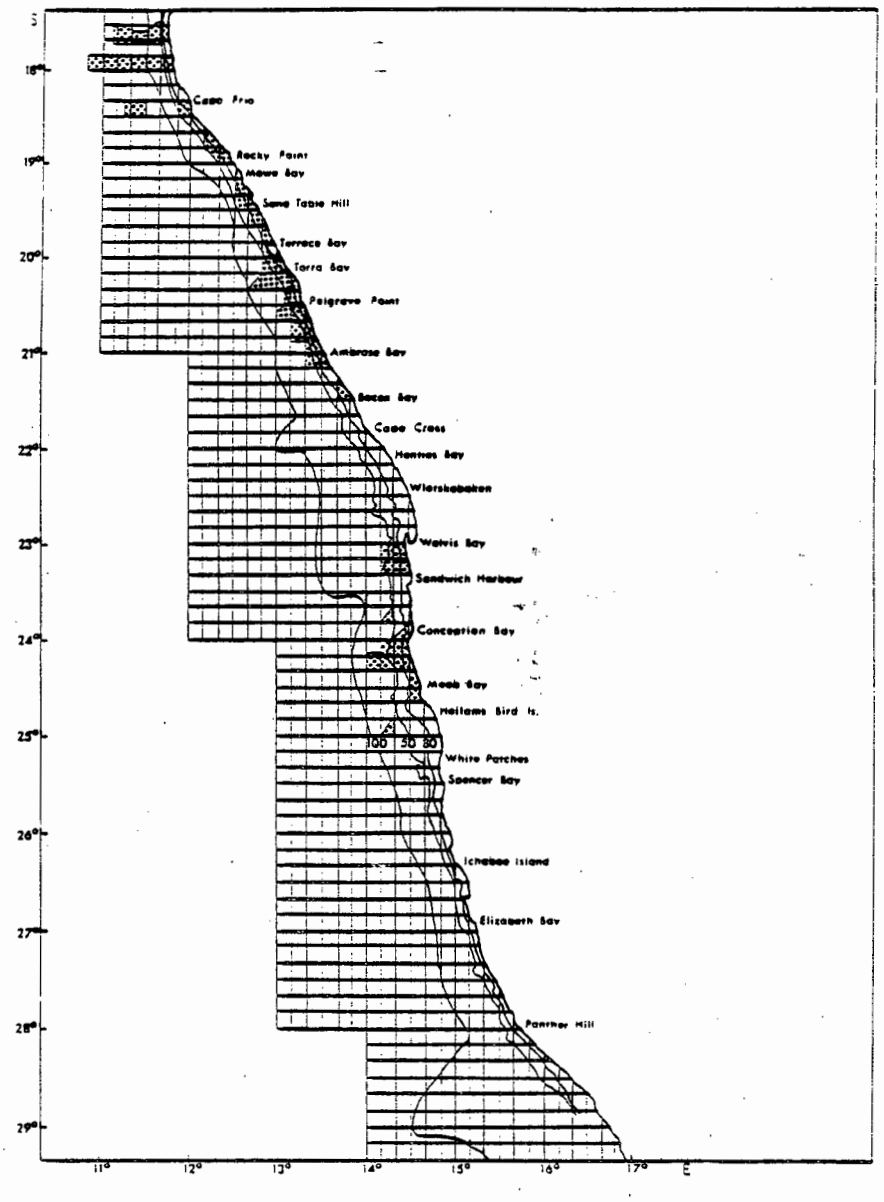


FIG. 1. Distribution of anchovy shoals by ten-mile grid squares, January 1982

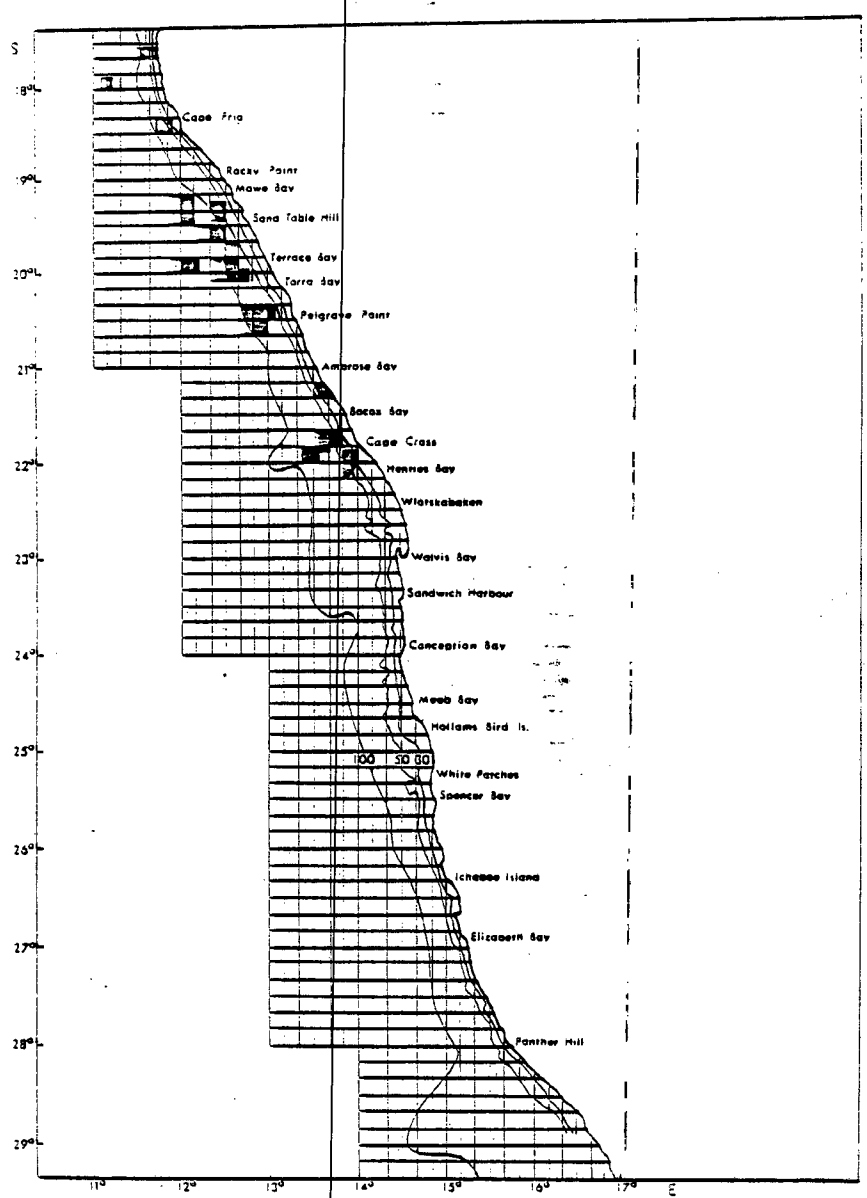


FIG. 2. Distribution of pilchard shoals by ten-mile grid squares, January 1982

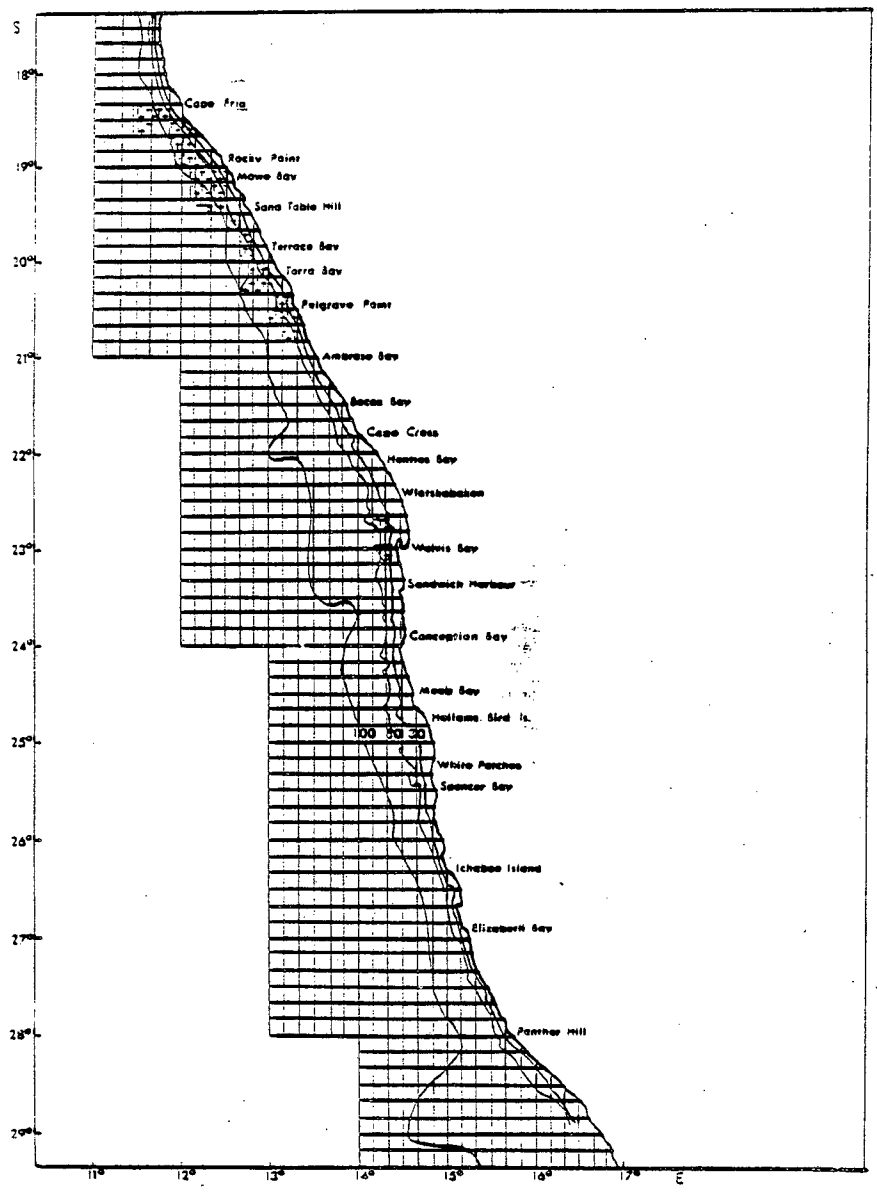


FIG. 3. Distribution of horse mackerel shoals by ten-mile grid squares, January 1982

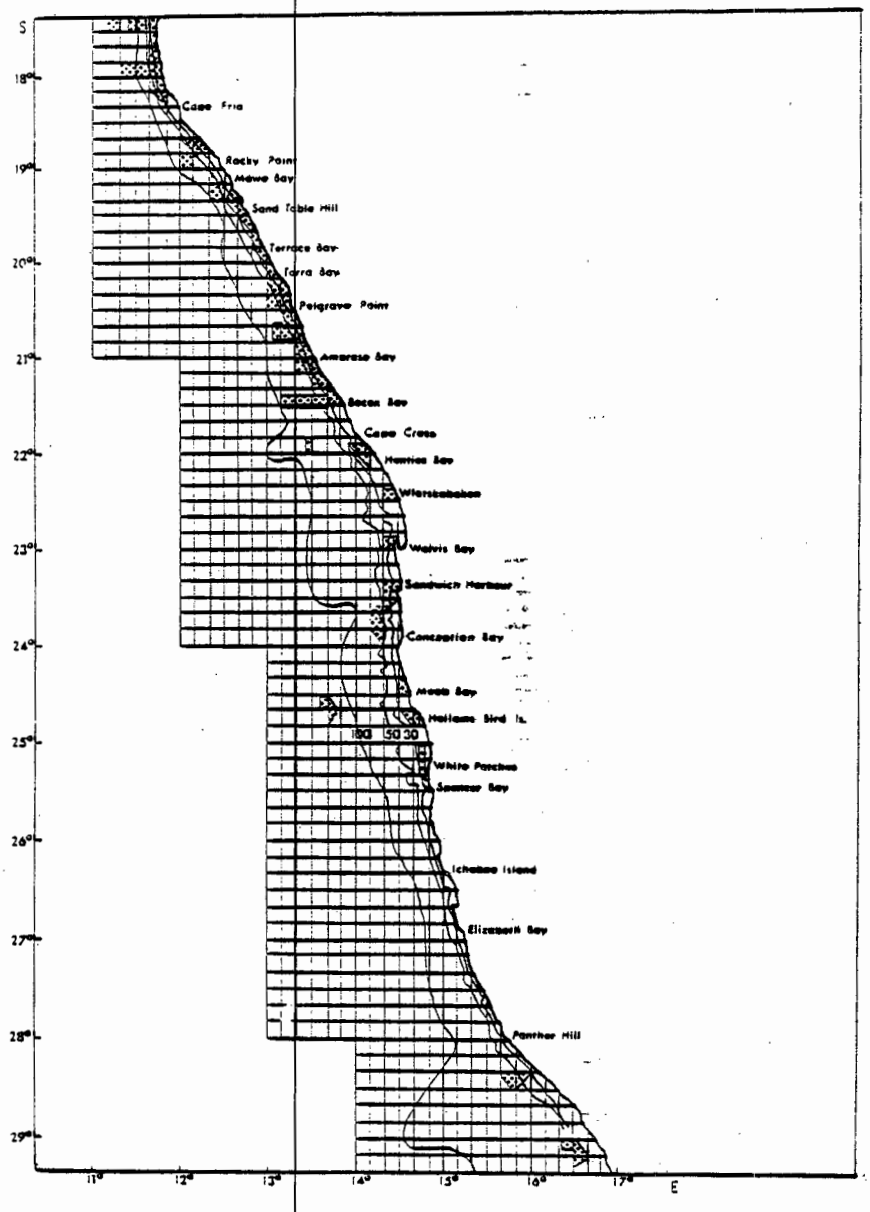


FIG. 4. Distribution of anchovy shoals by ten-mile grid squares, February 1982

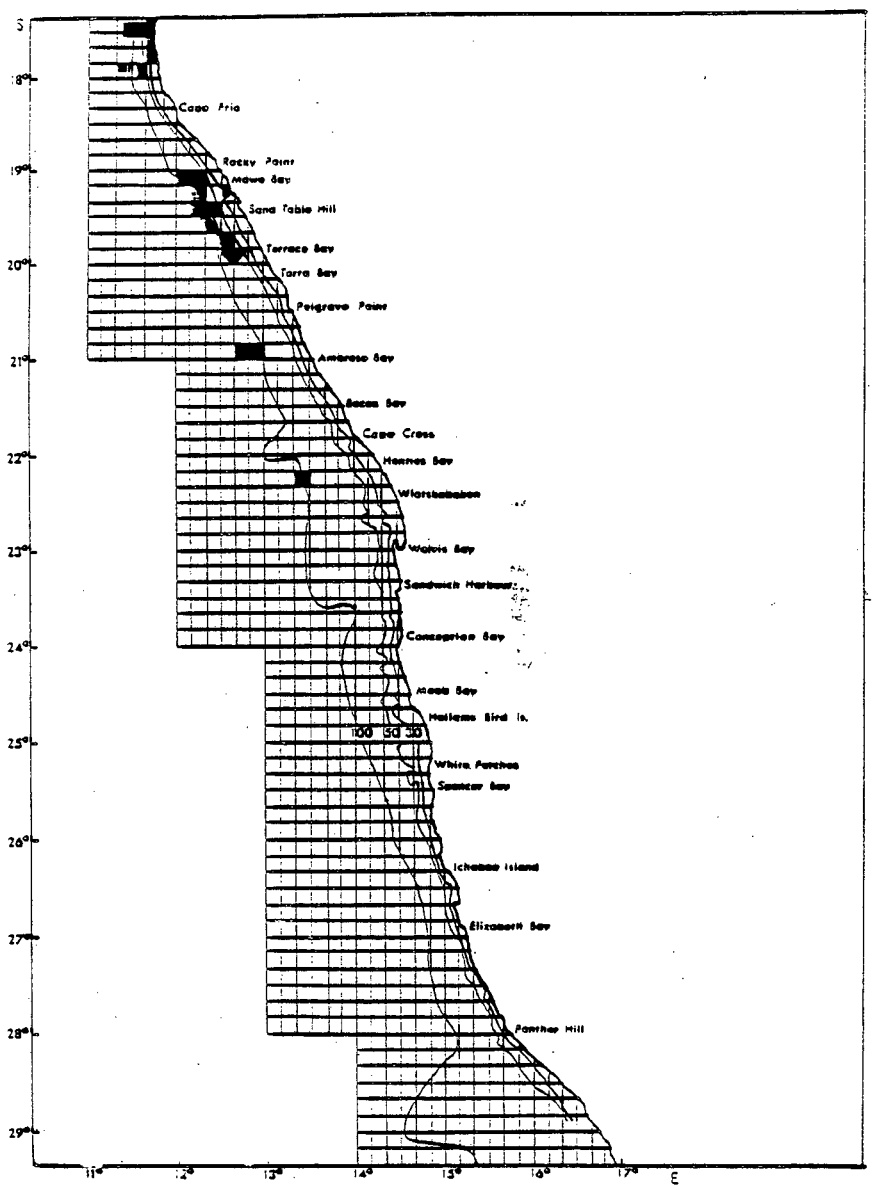


FIG. 5. Distribution of pilchard shoals by ten-mile grid squares, February 1982

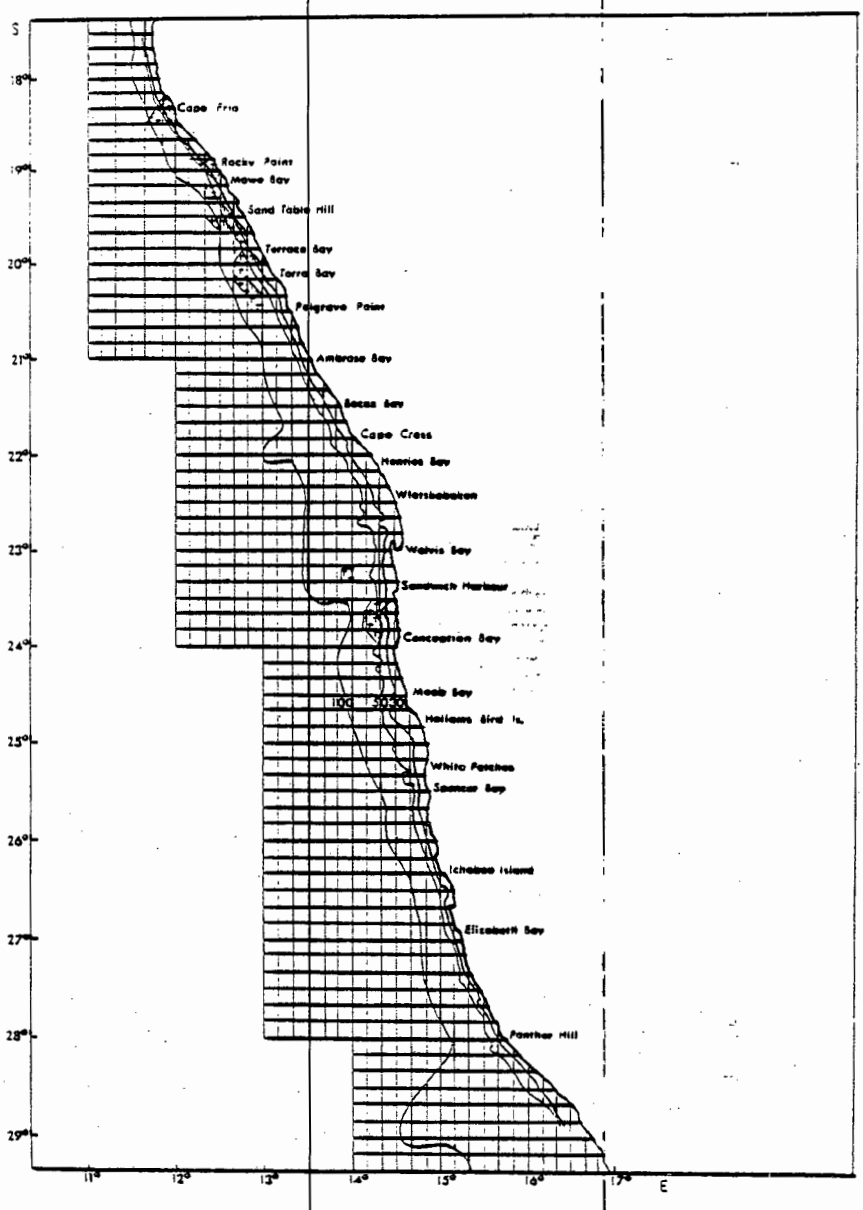


FIG. 6. Distribution of horse mackerel shoals by ten-mile grid squares, February 1982

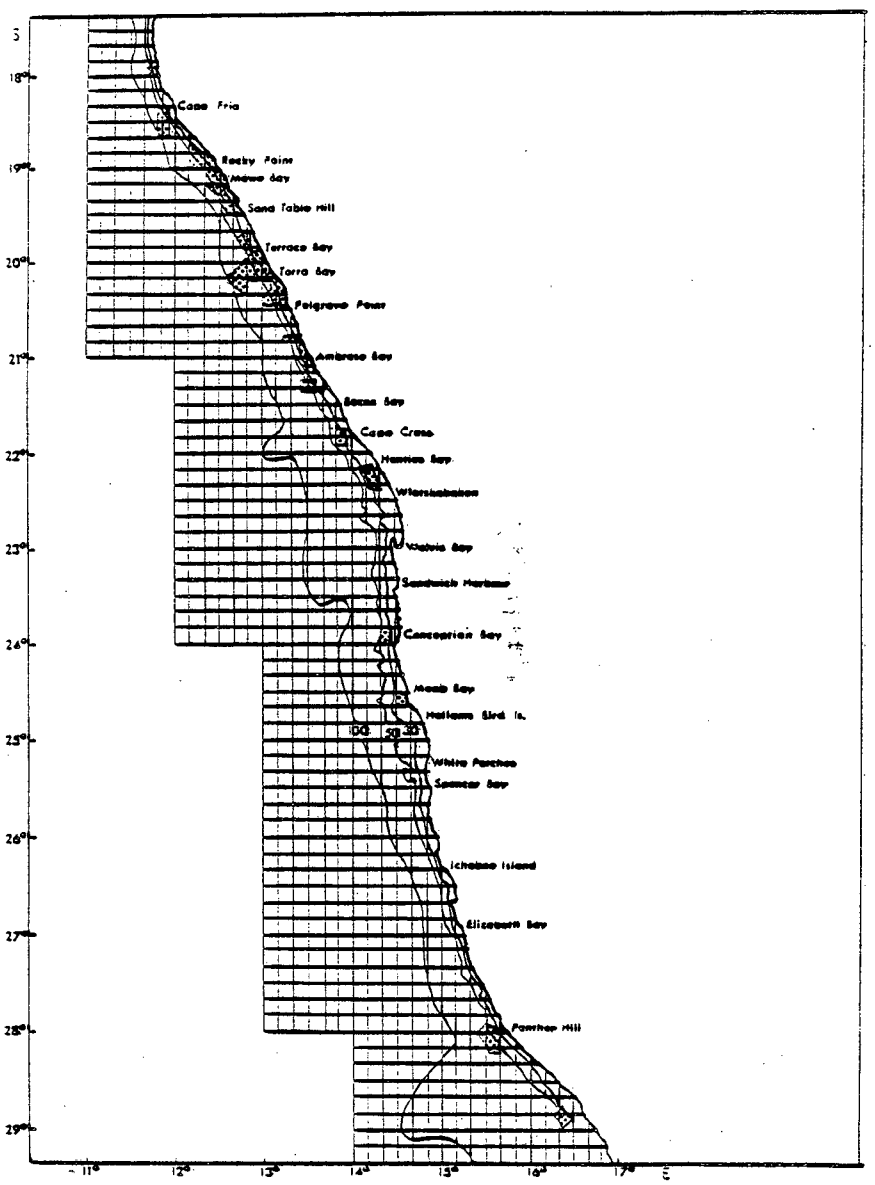


FIG. 7. Distribution of anchovy shoals by ten-mile grid squares, March 1982

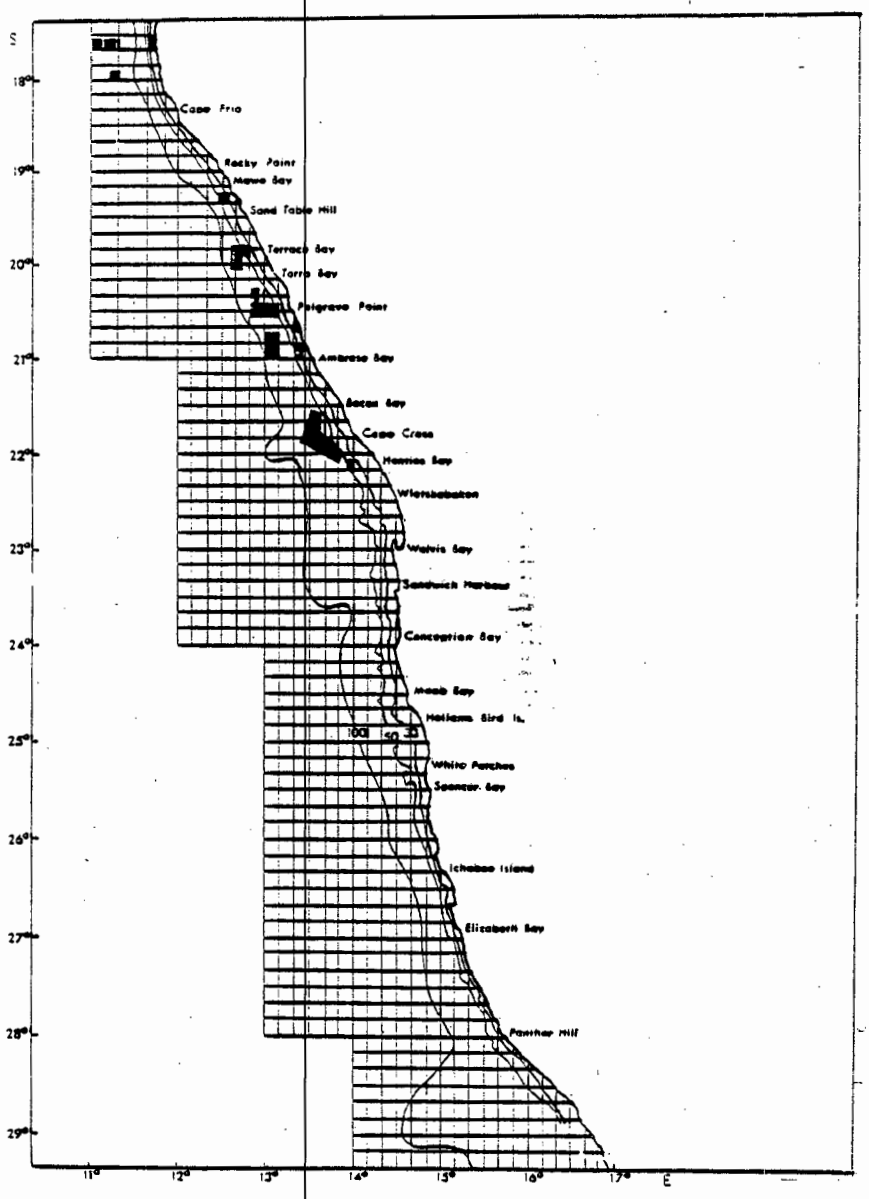


FIG. 8. Distribution of pilchard shoals by ten-mile grid squares, March 1982

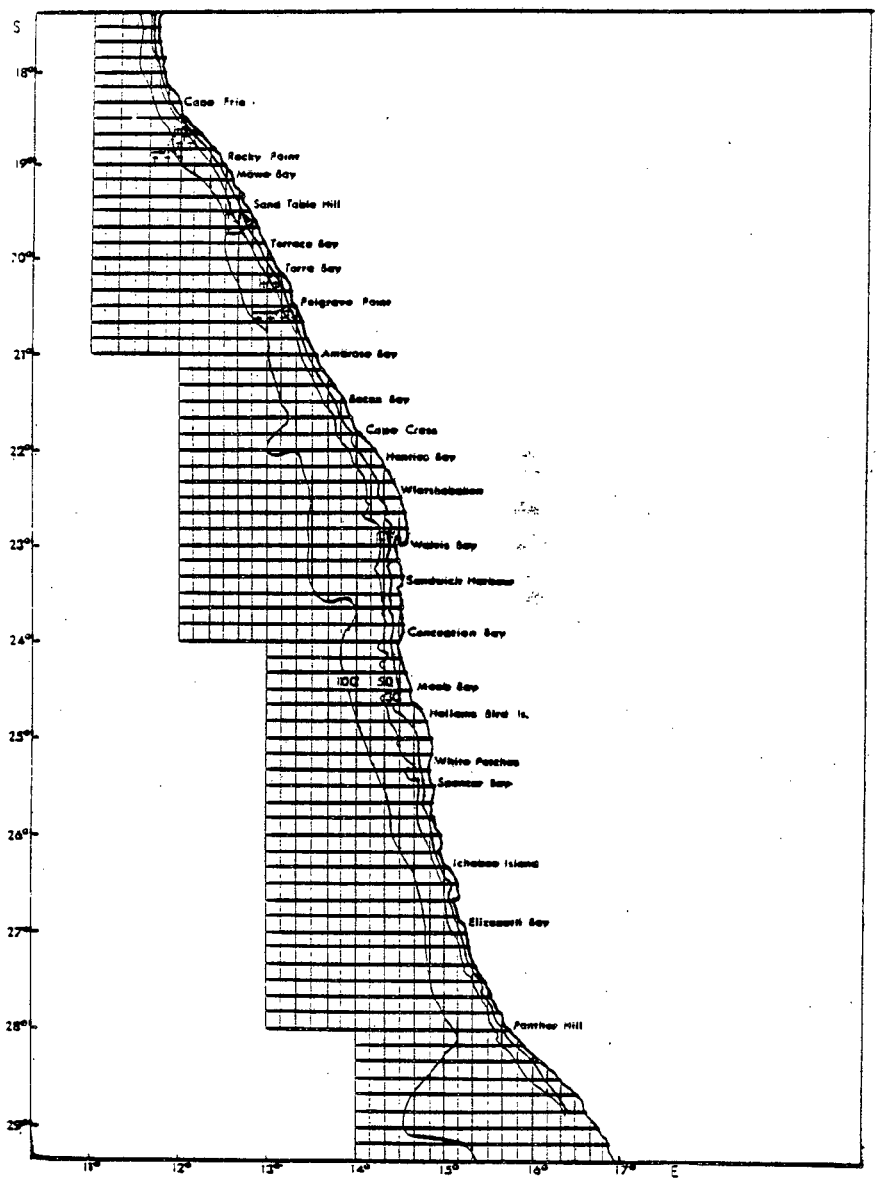


FIG. 9. Distribution of horse mackerel shoals by ten-mile grid squares, March 1982

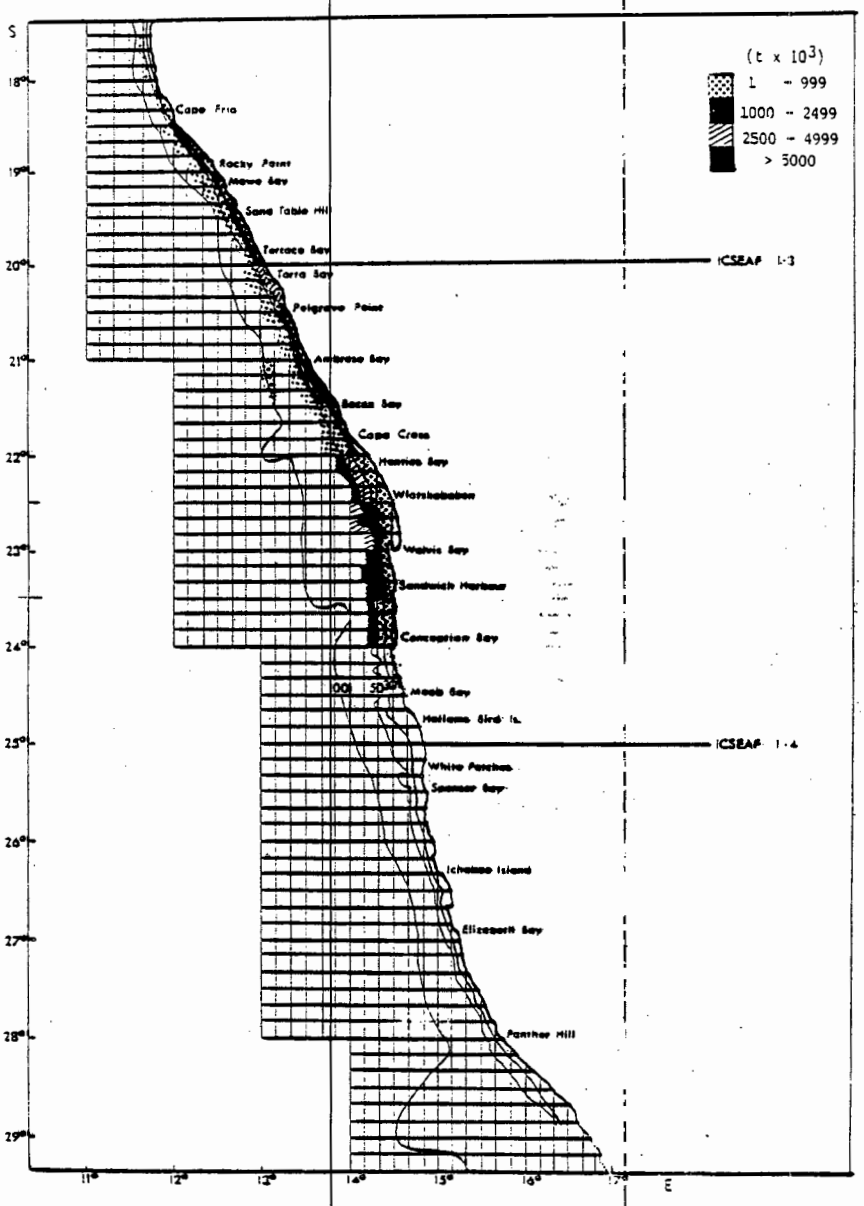


FIG. 10. Distribution of anchovy catches in 1982; totals per half degree of latitude compared to depth and distance offshore

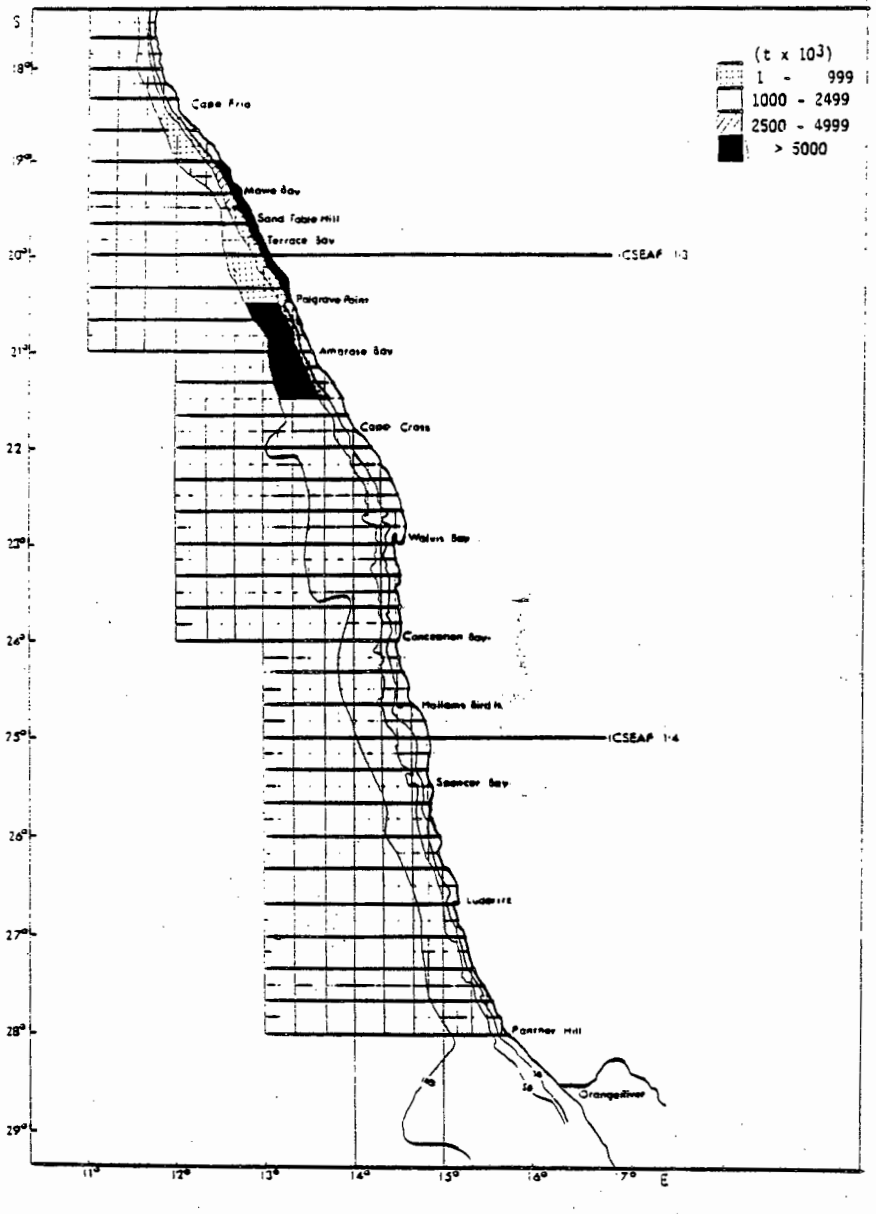


FIG. 11. Distribution of pilchard catches in 1982; totals per half degree of latitude compared to depth and distance offshore

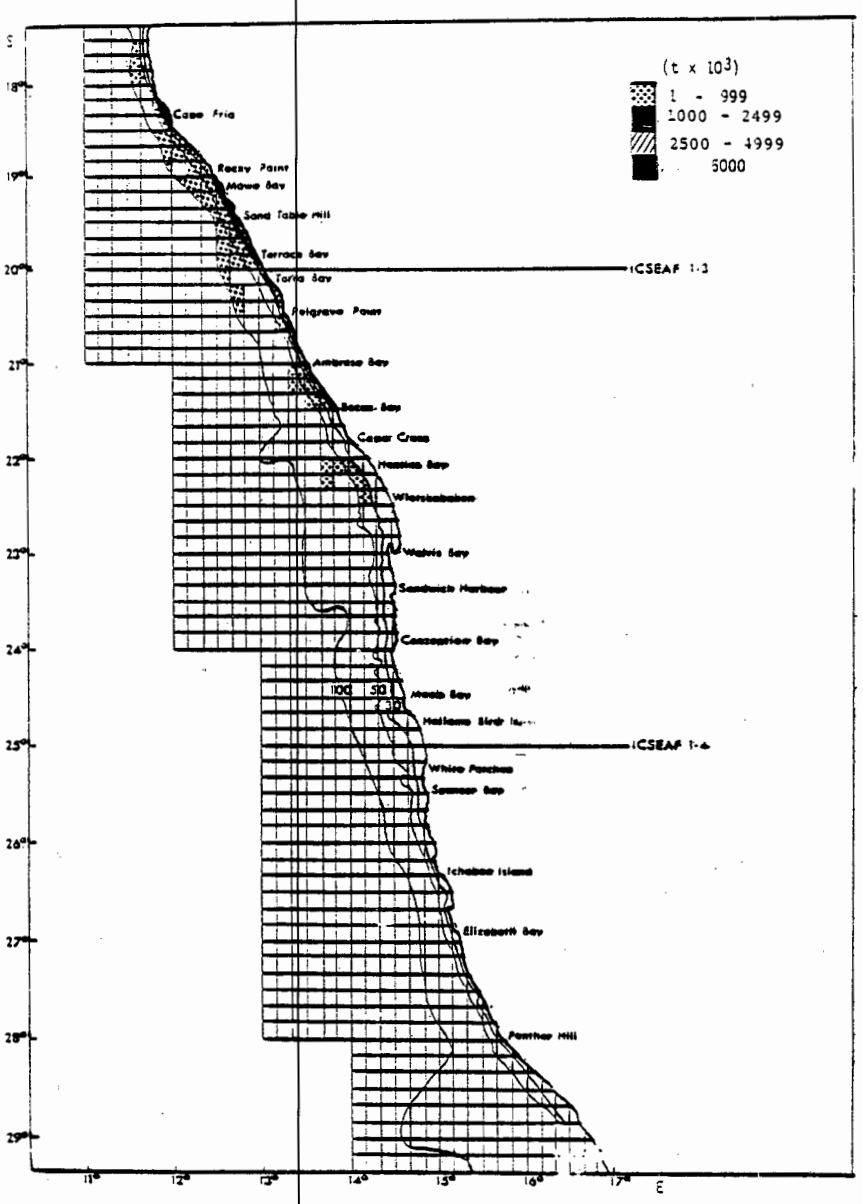


FIG. 12. Distribution of horse mackerel catches in 1982; totals per half degree of latitude compared to depth and distance offshore

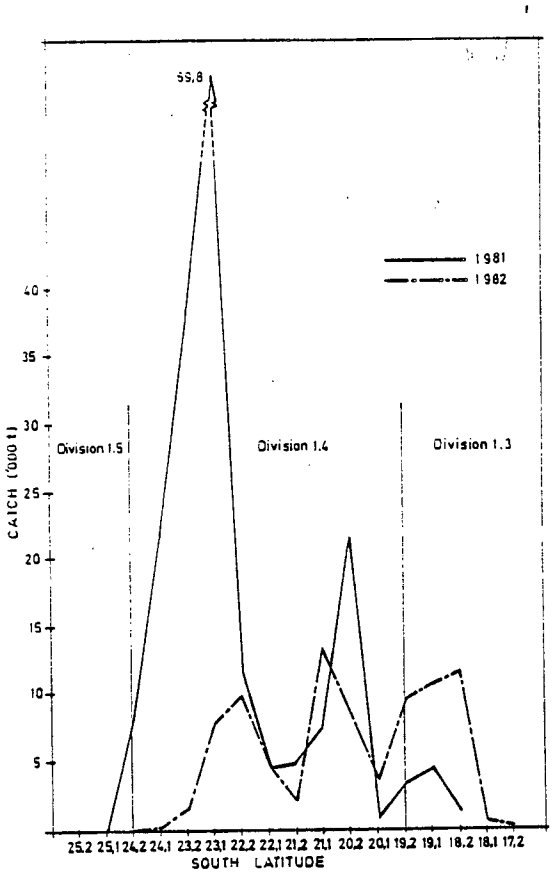


FIG. 13. Alongshore distribution of anchovy catches in 1981 and 1982 by half degree of latitude

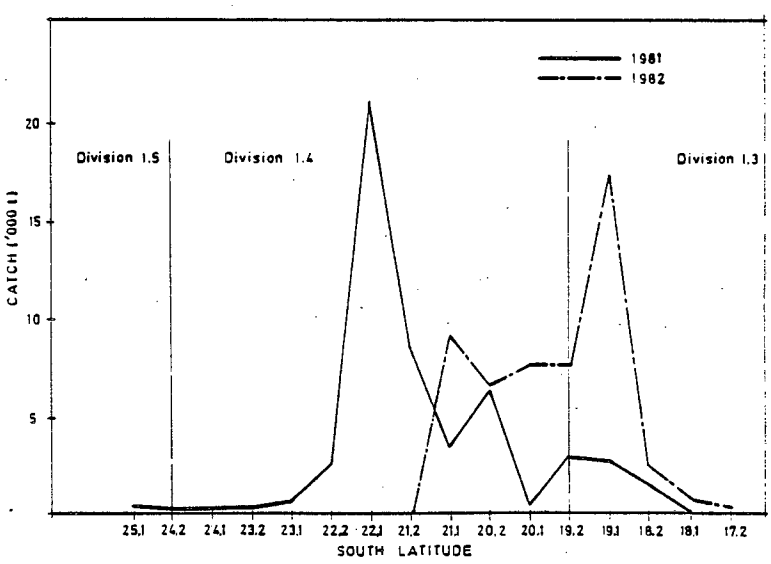


FIG. 14. Alongshore distribution of pilchard catches in 1981 and 1982 by half degree of latitude

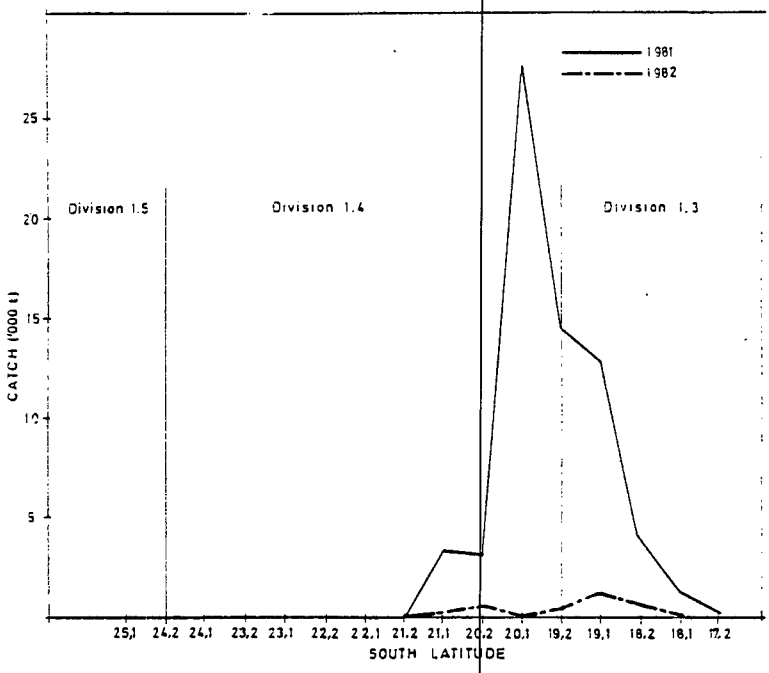


FIG. 15. Alongshore distribution of horse mackerel catches in 1981 and 1982 by half degree of latitude

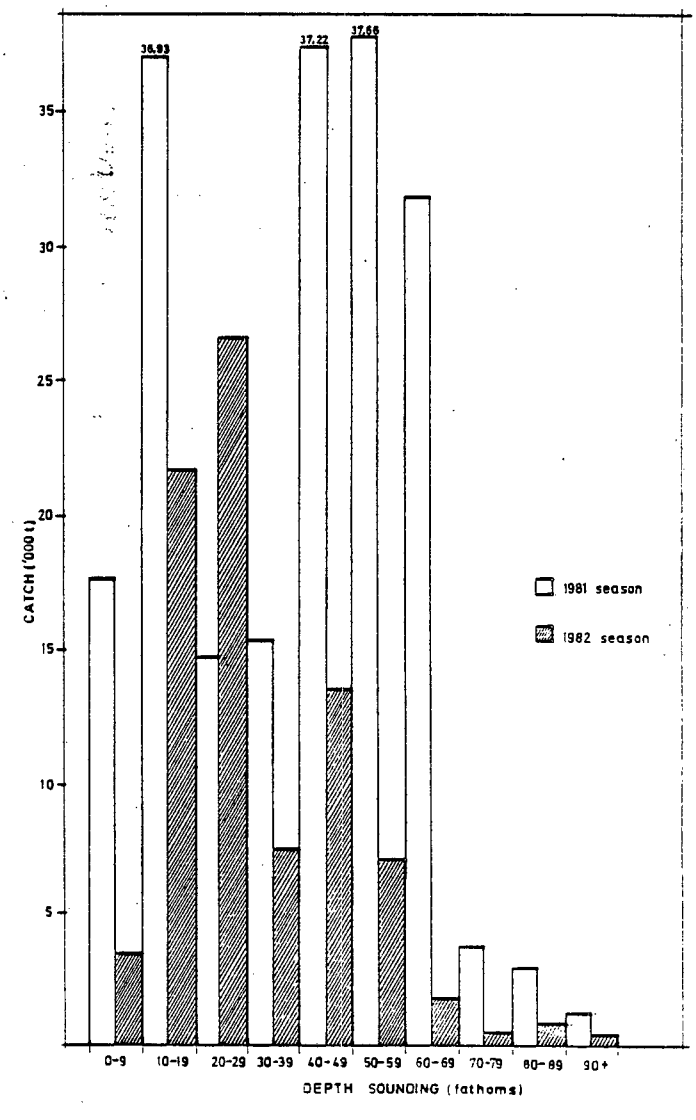


FIG. 16. Anchovy catch by depth in Divisions 1.3 + 1.4

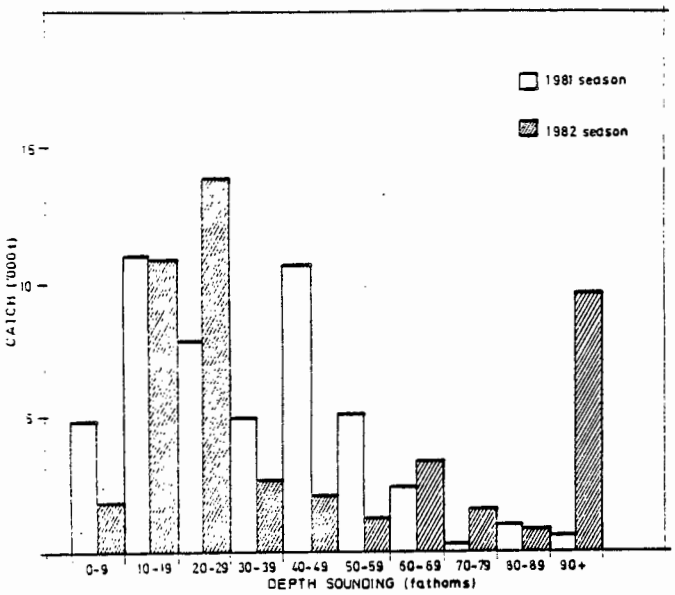
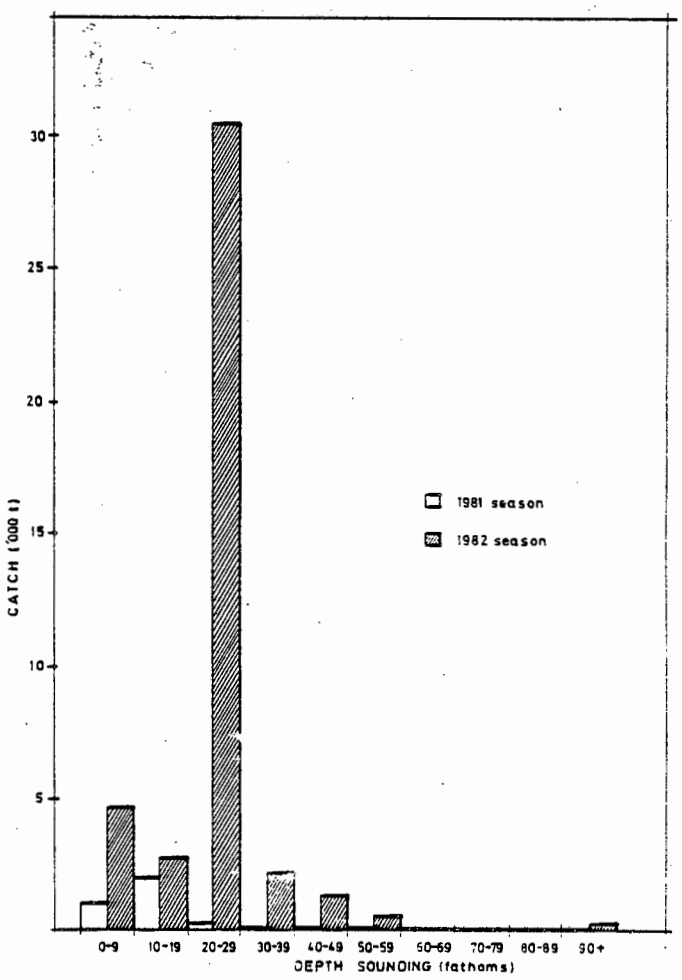


FIG. 17. Pilchard catch by depth in Divisions 1.3 + 1.4

FIG. 18. Horse mackerel catch by depth in Divisions 1.3 + 1.4



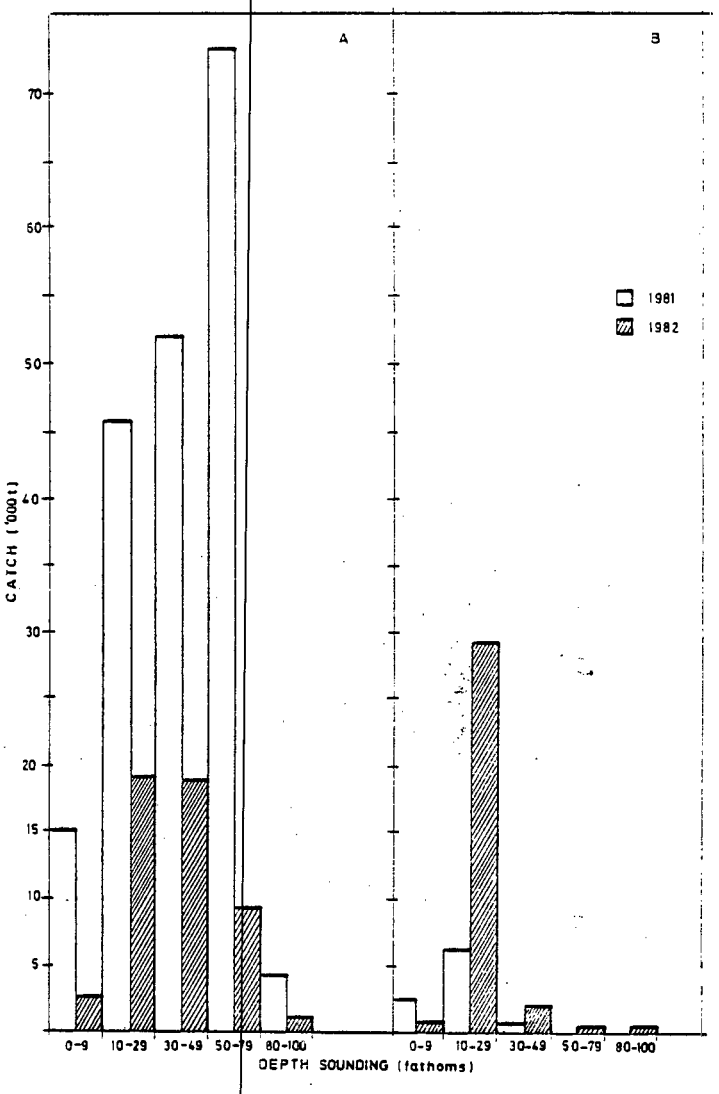


FIG. 19. Anchovy catch by depth in a) Division 1.4; and b) Division 1.3

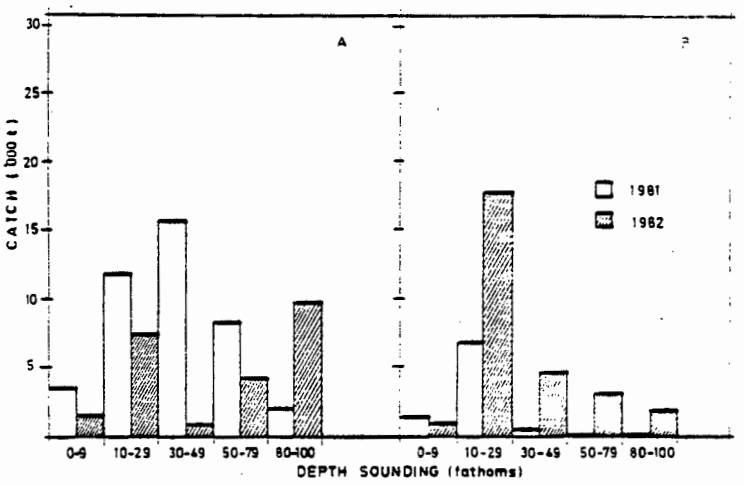


FIG. 20. Pilchard catch by depth in a) Division 1.4; and b) Division 1.3

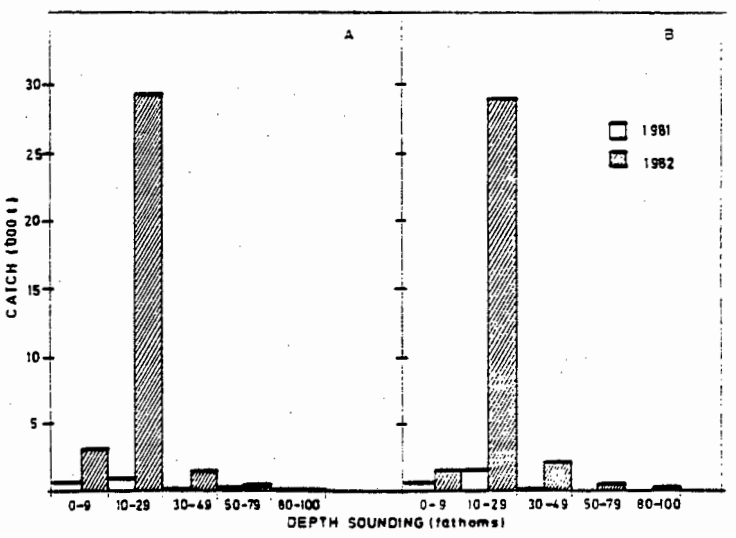


FIG. 21. Horse mackerel catch by depth in a) Division 1.4; and b) Division 1.3

Bay to the Orange river. Of the 10 055 observations of phosphate made between 0 and 10 metres, only 971 were from outside of the Danger Point to Lambert's Bay area.

In order to improve the nutrient data base, additional observations are also needed in the predominantly non-upwelling months (May to August), especially outside of the region bounded by 33°S, 35°S and 18°E.

The Marine Wind-field around the Cape Peninsula

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The presentation of the marine wind-field around the Cape Peninsula is based mainly on the data from five sea-borne radio anemometers and two coastal weather stations obtained during two experiments carried out at Olifantsbos and Oudekraal on the western side of the Peninsula. Additional data were provided by ships, pilot balloons and by an instrumented aircraft flying at 150 m. The data show a pronounced diurnal variation, forced by a land-sea breeze, with the intensity inversely proportional to the distance offshore, but also a longshore variation in the character of this forcing. For example, at Oudekraal the flow seldom becomes onshore, the downslope jet is merely decelerated by this forcing.

The offshore gradient of the wind at Olifantsbos appears to be dependent on the wind direction, with the greatest gradient occurring when the flow is oblique to the coastline with low, probably turbulent, winds at the foot of the mountains. This is essentially the same as the 'cape effect', which is found both on a small scale, as at Olifantsbos, and on a large scale, such as at the Peninsula, where the wind stress maximum shifts from northwest of Cape Town under southerly conditions to west of Cape Point under southeasterly conditions. Topographic forcing of the streamlines also shows up in a shift of wind direction of as much as 45° between Olifantsbos and Oudekraal.

We conclude that the wind-field around the Peninsula is overwhelmingly dictated by the very pronounced and varied topography.

Circulation over the Shelf Zone of the Cape Peninsula Region

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Four techniques of current measurement, including geostrophic calculation, measurements from moored current meters, current profiling from a drifting ship, and drogue tracking have been used to study the circulation over the shelf zone of the Cape Peninsula. The results of this work are summarized in Fig. 1.

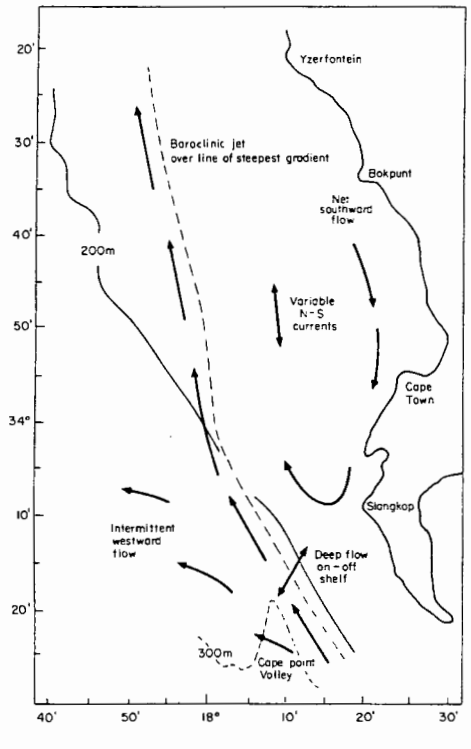

Fig. 1. Current patterns in the vicinity of the Cape Peninsula.

A permanent northward-flowing baroclinic jet exists over the line of steepest gradient on the shelf edge, which corresponds roughly to the 200 m isobath. Current meters moored on the shelf coastwards of this jet, show a north to southward switching flow, with a net southward flow closer to the coast. The southward-flowing current has a retroflection zone west of Slangkop, where it turns and is entrained in the shelf-edge jet. The existence of southward flow within a broad belt 30 km wide off the coast is seen also on isotach sections obtained from current meter profiling on lines north of Slangkop.

Seawards of the shelf-edge jet, a westward motion is observed. This flow is variable and probably occurs when the shelf-edge jet accelerates under the action of atmospheric forcing. In the deeper layers, an on-shelf, off-shelf motion occurs at the shelf edge near the Cape Point Valley. Water as cold as 5°C rises up the valley and onto the shelf and then slides off again within a few days. A good correlation between this motion and local winds has been observed, but a phase difference which develops after a few days suggests that these phenomena are not directly related, but are manifestations of atmospheric forcing on a large spatial scale of some hundreds of kilometres. The predominantly north-south oscillation in current meter records, with a period of a few days, indicates that considerable sea-level adjustment in the longshore direction occurs under atmospheric forcing.

Satellite Sensed Internal Wave Features off the South-west Cape Coast

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Six out of eighteen clear-day Landsat images of the south-western Cape coastal zone show wave-like formations with separations ranging from 1.5 to 7 km which are suggestive of internal wave action. Two distinct features are observed. One pattern, with a wavelength of about 2.5 km, appears to be radiating eastwards and westwards from a shallow feature some 20 km south-east of Cape Point. These short, crested waves fan out and appear to be refracted around the point and into False Bay. They are probably actively propagating waves manifest to the satellite by a change in surface roughness. Apel *et al.* (1975) have previously reported similar formations in the vicinity of the Childs Bank off the Cape west coast.

The second pattern is broader and more diffuse with variable wavelength. The most likely explanation for this banding is that internal waves have moved up the shelf slope, become unstable and have broken into bands of turbulence. This may be a mechanism for supplying nutrients to the euphotic zone and it is not impossible that the banding evident on the Landsat imagery may be related to zones of enhanced biological activity. These waves are all observed coastwards of a chlorophyll front for November-December obtained from Nimbus-7 CZCS data.

Internal waves can be generated at the shelf edge by tidal flow over the bottom. A time-dependent longshore Reynolds stress is produced which interacts with the Coriolis force to cause a cross-shelf mass flux. The constraint on divergence at a steeply sloping bottom causes a wave to be generated which moves up the shelf. In a sea of constant stratification without a significant pycnocline, the amplitude of such waves can grow and become unstable at the surface. All six images cited occur between October and November when the stratification at the edge of the Agulhas Bank is weak. Furthermore, five cases occur at periods of spring tide.

All six examples occur during periods of southerly wind following the ridging of the South Atlantic High round the continent, but this is precisely the period during which clear-day images are obtained and no significance should necessarily be attached to atmospheric forcing as a mechanism of internal wave generation. Little information is available on currents over the Agulhas Bank, but the slope of isopycnals observed along the shelf edge points to the existence of baroclinic shear, which would act as a further destabilizing mechanism on waves propagating up the shelf.

Ecology of Pilchard and Anchovy Shoals off Namibia

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Hydroacoustic surveys of the pelagic shoals off the Namibian coast have been conducted regularly from 1978/79 to 1982/83. Shoals were sampled from purse-seine catches, and their distribution and movements were compared with concurrent environmental data. Statistics pertaining to the

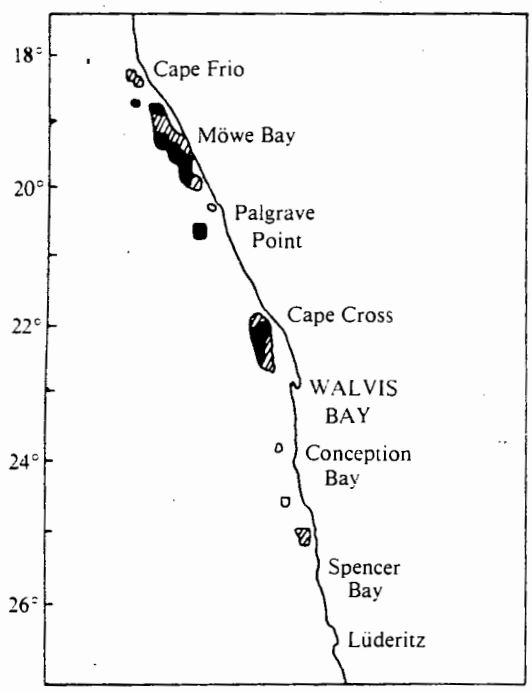

Fig. 1. Pilchard distribution as detected by hydroacoustic surveys in the summer of 1981.

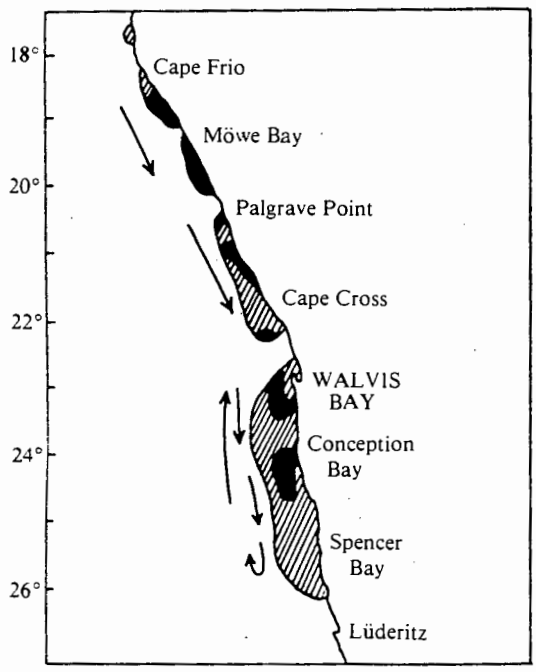

Fig. 2. Anchovy distribution as detected by hydroacoustic surveys in the summer of 1981. The southward progression and its reversal between Spencer Bay and Ichaboe Island are clearly evident from January to March.

Namibian pelagic fishery were plotted geographically and compared with monthly environmental monitoring data. Thus vertical and geographical ecological profiles for pilchard and anchovy shoals could be compiled. The maps show the pattern of recruitment in late summer and autumn of 1981 (Figs 1 and 2). There is a clear tendency among anchovy shoals to move southwards from the nursery areas. South of Walvis Bay shoals of juveniles move southwards from January to March. In autumn these recruits (now larger) turn about before Lüderitz and gather together off Walvis Bay, where they are supplemented by shoals of recruits from the north. Peak winter catch distributions confirm this concentration of recruits (Fig. 3).

Patterns of vertical movements by anchovy and pilchard are not always consistent nor as distinct as with, for example, lanternfish. Anchovy shoals sink to the midwater zone during the day and rise to the surface at night when they form broad sheets of smaller shoals. Pilchard usually form large shoals in the midwater zone by day and smaller shoals at the surface at night. Anchovy in particular tend to form large concentrated shoals close to the surface at dawn and dusk.

Sudden changes in environmental conditions, such as a temperature drop of 1° or 2°C, which may affect phytoplankton availability, and rapid depletion of dissolved oxygen, may disrupt normal shoal behaviour. For example, a large anchovy shoal monitored in June 1981 showed regular behaviour, undisturbed by any specific hydrological condition until the rapid development of anoxic conditions throughout most of the water column caused evacuation on the second day (Fig. 4).

Anchovy prefer shallower waters than pilchard. This is particularly discernible during the summer spawning peaks when anchovy shoals — and eggs[1] — are almost exclusively confined within the 50 fathom contour. In winter 1981 most shoals were caught within 60 fathoms and within 30 fathoms in 1982.[2]

Unseasonably cold temperatures in February 1982 and low phytoplankton densities in the south may have reduced the normal shift of anchovy shoals, as was reflected in the catch distribution. Pilchard shoals show a delayed response to changes in phytoplankton concentrations. Anchovy, being closer to shore, are generally found among the densest phytoplankton, whereas pilchard are found among the lower concentrations where there is more zooplankton.

Shoals respond to heavy predation and fishing pressure by dispersing and re-congregating further off. This behaviour was observed by following shoal movements southwest of Walvis Bay in June 1981 and by monitoring the fishing fleet. There is some evidence that the very high predation pressure from snoek and mackerel in January and February 1982 had a detrimental effect on anchovy spawning success south of Walvis Bay, by depleting the number of juveniles and scattering the survivors widely during the critical stages of early shoal formation, thus reducing their feeding and survival efficiency.

There appear to be few hydrological limitations on the distribution of pelagic shoals off Namibia. However, there is a tendency towards favoured areas of optimal congregation termed 'basins' by MacCall (personal communication). Improved quantitative assessment of the recruiting stocks is required for fisheries management. To this end an intensive investigation of the recruitment and behaviour of anchovy shoals is being carried out bet-

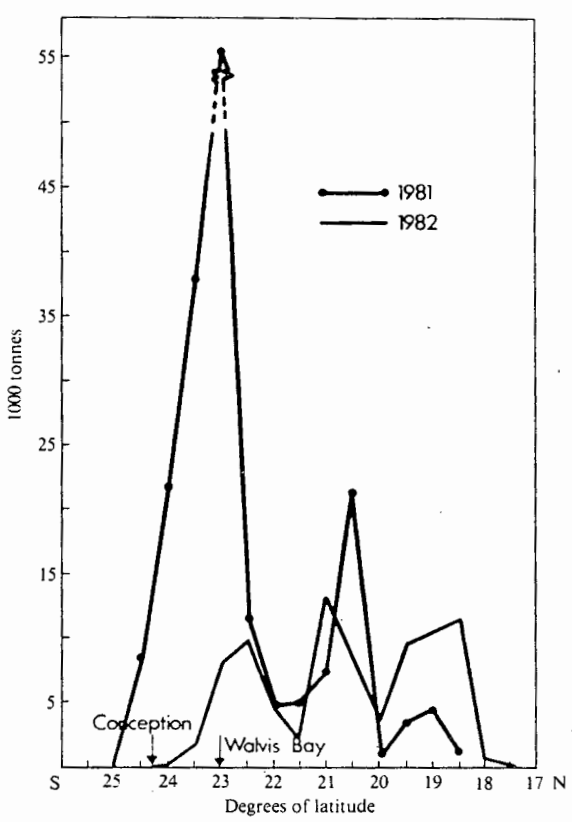

Fig. 3. The longshore distribution of anchovy recruits caught commercially in the winters of 1981 and 1982.

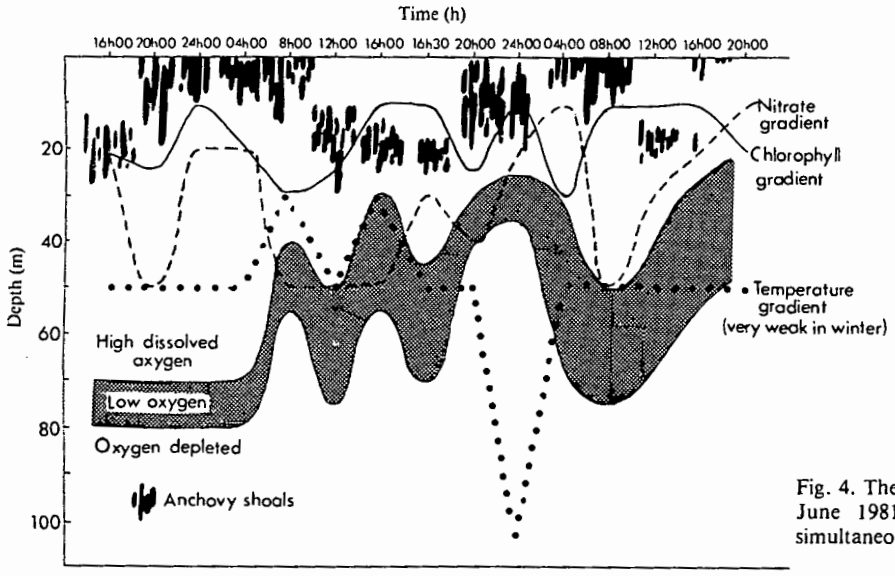

Fig. 4. The vertical movements of anchovy shoals monitored in June 1981 relative to hydrological conditions monitored simultaneously every 4 hours over a 52 hour period.

ween 23° and 29°S. Surveys will extend further offshore than in the past. More efficient methods of sampling juvenile fish (pre-recruits) by means of midwater trawls will be tested in addition to monitoring of the associated hydrological conditions.

1. Le Clus F. (1983). See abstract p. 143.
2. Cruickshank R.A. (1982). Distribution of pelagic fish shoals determined by acoustic surveys, 1981 – 1982, and their relationship to environmental factors. *Colln scient. Pap. int. Commn SE Atl. Fish.* 10 (in press).

Lanternfish Ecology in the Benguela Current System

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There is a large population of myctophid lanternfish in the Benguela Current system. *Lampanyctodes hectoris* is the overwhelmingly dominant species off Namibia. Also common is the gonostomatid lightfish species, *Maurolicus muelleri,* which is most common in the St Helena Bay area. The lanternfish species *Symbolophorus boops* and *Diaphus* spp. are infrequently encountered, usually in the far north off Cape Frio. Ecologically, lanternfish and lightfish show the same behaviour. They display a distinctive circadian pattern of vertical migrations, rising from deeper than 200 m during the day to close to the surface at night. These migrations to and from the surface are stimulated by light intensity, as can be seen by their approach to the surface after sunset and their response to sunrise (as opposed to dawn) and overcast daylight conditions. The main purpose in rising to the surface is to feed, as evidenced by the full stomachs in all specimens examined from purse seine catches.

The length and weight distributions of specimens caught in the upper 50 m at night by means of bongo nets are illustrated in Fig. 1. Most specimens range in length between 20 to 70 mm, although the extremes observed were from 10 to 120 mm. Juveniles and subadults grow 15 to 20 mm in two to three months during the summer recruitment period. Recruitment to the stock begins when the fish are between 10 and 15 mm in length. Peak recruitment occurs in January and February. The ratio of fish less than 40 mm (juveniles) to those more than 40 mm (subadults) in length changes inversely from October (spring) to January (summer), then reverses in March and April (autumn). In January the ratio of juveniles to subadults is 5:1 but may be 10:1 in some years. Fish less than 65 mm long are sexually immature. Spawning begins in late winter and reaches a peak in spring during the major upwelling season off Namibia.[1]

The extensive distribution of lanternfish off Namibia has been mapped. The shoreward limit of their range corresponds fairly closely with the 200 m contour line in the midshelf region. That is, lanternfish generally occur 30 or more miles offshore in deep water. However, samples have been collected close to the coast at intermittent points north of Meob Bay and frequently south of Lüderitz. Lanternfish have been recorded from deeper, oceanic waters but their greatest density seems to be over the outer shelf, particularly where there are deep canyons cutting in close to the coast. Mesopelagic lanternfish and lightfish have potential as an alternative fishery resource to supplement anchovy and pilchard. In 1973, lanternfish contributed 10% of the total South African pelagic landings. However, myctophids display a cyclic variation in population density which, combined with variable fishing effort, has not so far provided a stable fishery. Migration patterns mean that the fish are exploitable pelagically for only a brief part of the day. Midwater trawling, although possible during daylight hours, would require small meshes and may therefore harm both the mesopelagic and demersal fish populations. We have insufficient data to know whether lanternfish play a key role in the ecological web of the Benguela upwelling system.

Present research priorities include: (1) investigation of the species diversity in the Benguela Current; (2) analysis of the feeding ecology of each species; (3) study of the growth and age structure of the west coast population; (4) learning why the population density varies as it does; (5) determining the depth-dependence of population; (6) determination of stock size.

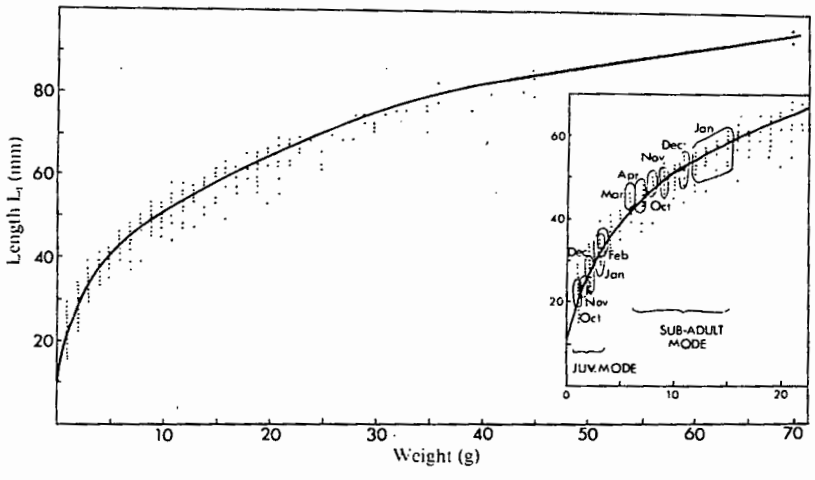

Fig. 1. Lanternfish growth curve from bongo samples collected from November 1979 to March 1982. *Insert*: Monthly size range plotted over the same curve to illustrate seasonal growth rate.

Factors affecting the range and direction of these movements and causes of recruitment failures such as seen in 1982 and 1983 are discussed. It is proposed that the major factors are (i) TEMPERATURE regimes, (ii) FOOD AVAILABILITY - mainly phytoplankton which is also temperature linked, (iii) AVOIDANCE of COMPETITION intraspecifically as well as inter -specifically, and (iv) PREDATION PRESSURE when the recruits are most vulnerable to disruption.

The general distribution pattern for optimal conditions is stressed (slide 6). The results of an anchovy recruitment survey between Walvis Bay and the Orange River are presented (slide 7). The link between the shoals found up to 50 miles north of the Orange River and those found south of the Orange River in the May 1983 acoustics survey, reported here by Mr Ian Hampton, is shown. This corresponds with previous data from earlier surveys extending as far south as the Olifants River. Monthly surveys showed shoal groups detected between Chamais Bay and Port Nollo th moved steadily southward from December to August but finally remained fairly consistantly between Hnodeklip Bay and the Olifants River.

The absence of any juvenile shoals from Chamais Bay to Walvis Bay and the subsequent lack of fishing success except on adult anchovy stocks north of Palgrave Point, indicates an almost complete recruitment failure off S.W.A. for 1983.

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Collect. Sci. Pap. Int. Comm. SE. Atl. Fish.
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ANCHOVY RECRUITMENT OFF SOUTH WEST AFRICA SOUTH OF WALVIS BAY

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INTRODUCTION

Hydroacoustic surveys of pelagic fish distribution conducted off South West Africa/ Namibia from 1978 to 1982 (Cruickshank 1983a and b) showed that a detailed investigation of anchovy recruitment between Walvis Bay and the Orange River (ICSEAF Divisions 1.4 and 1.5) was necessary. Determining the status of the anchovy stock off the Orange River and its relationship, if any, to the recruits that gather in the Walvis Bay area (ICSEAF Division 1.4) each winter was of particular interest. An intensive hydroacoustic survey was conducted from the Orange River to Walvis Bay by the R/S "BENGUELA" in April 1983, and the results are reported in this paper.

METHODS

The survey grid, shown in Figure 1, extended from 2 to 95 nautical miles offshore per line, except for a few short lines of 50 n miles each. Up to six regularly spaced stations per line were surveyed using rectangular midwater trawls (RMT's) to sample the upper 100 m. Temperatures were recorded at the surface and down to 3 m from the bottom with a bathythermograph. A 50 m vertical plankton haul was also made with an N50V net; and, at night only, a neuston net was towed at the surface.

Approximately every other line (half degree of latitude), stations at 10, 25, 50 and 75 n miles were intensively sampled for hydrological parameters, namely, dissolved oxygen, salinity, temperature, chlorophyll, nutrients, and diatoms. Ad hoc RMT hauls were made, as required, to identify shoal targets.

RESULTS

The distribution of juvenile anchovy shoals is depicted in Figure 1. No significant quantities of anchovy were detected from 23° to 27°15' S (ICSEAF Divisions 1.4 and 1.5). The distribution of lanternfish (myctophidae) in this area is also given.

Hydroacoustic records showed shoals of anchovy juveniles up to 30 miles from shore between the Orange River and Chamais Bay. These shoals were small and widely scattered. A large group of juvenile anchovy shoals was found in open scattering layers at the surface mainly close inshore off Panther Hill. These did not, however, represent viable fishing quantities. All pelagic shoal targets were detected within the upper 30 m between 5:00 p.m. and 1:00 a.m.; no targets were detected during daylight hours. Shoals and scattering layers were successfully sampled by horizontal as well as oblique tows of the RMT2 and RMT8 gears and by means of surface tows with the neuston net.

No sign of any significant shoals was detected between Chamais Bay and Walvis Bay. A few minor scattering layers and shoal scratches were detected near Sylvia Hill and Hollams Bird Island, but all other scattering layers were attributed to either myctophidae, gobiidae, or medusae. The latter were a particular problem. No anchovy eggs were found in the samples.

A few juvenile anchovy and horse mackerel were collected 15 and 25 n miles west of Sandwich Harbour. These two instances were the only definite indication of recruitment in the Walvis Bay/Conception Bay area south of 23° S.

Length frequencies by station are plotted against latitude in Figure 2. Modal standard lengths (L_C) of anchovies caught at the various stations ranged from 45 to 65 mm but samples included a range of sizes, from larval (15 mm) to adult (100 mm). The length frequencies showed a consistent, sharp cutoff in fish lengths smaller than the mode and a progressive decrease in numbers of fish greater than the mode. Considering that a similar pattern was obtained for both the RMT nets as well as for the neuston net, it is unlikely that escape or net avoidance by smaller juveniles and larvae was responsible for the observed trend. It is suggested that the pattern indicates the

completion of spawning, with the result that only pre-recruits and a few late-stage larvae were present.

Most of the juveniles less than 30 mm long were caught 10-25 miles offshore. This, and the trend by the length frequencies to increase inshore and southward towards the Orange River, suggests an inshore and southward movement of these juvenile anchovies. Such movement was confirmed twice. Firstly, during the return journey attempts to relocate and resample this population failed. One week later, in May, a similar acoustic survey conducted from the Orange River south to Cape Point found juvenile anchovies of corresponding size classes off Hondeklip Bay and further south (Hampton, Sea Fisheries Research Institute, personal communication).

The majority of all positive stations (for anchovy) were inside 25 n miles, with a peak (70 %) within 15 n miles of shore (Figure 3). This agrees with earlier findings (Cruickshank 1983a) for shoals on the major fishing grounds off South West Africa. Pooling all the samples for a given degree of latitude, regardless of distance from shore, shows a distinct shift in the modal peak from 35 to 45 mm, with southward progression. A second mode at 65 mm (L) also appears in the south (Figure 4).

Temperatures at the surface and at 25 m (maximum depth of shoals) for all the anchovy catches are plotted against latitude in Figure 5, which shows that the shoals all occurred at or well above the 14 °C isotherm chosen by Boyd and Cruickshank (1983) to define their environmental basins for autumn and winter. When length distribution was compared to temperature, a distinct predominance of early juveniles (20-50 mm) was found at temperatures between 15,5 and 17,0 °C, with greatest abundance at 15,5 and 16,5 °C. In contrast, older specimens (60-85 mm) were collected at 14,0 °C, which is in keeping with the trend towards an inshore movement as length increases. No juveniles were found at temperatures above 18,0 °C or below 12,5 °C. They therefore have what is termed an encapsulated temperature distribution in this region. The cold waters of less than 13,0 °C from north of Chamais Bay to Ichaboe Island formed an effective barrier to the shoals moving in that direction; and, south of the Orange River, Hampton (Sea Fisheries Research Institute, personal communication) found a tongue of cold water temporarily trapping anchovy shoals near Hondeklip Bay as they moved southward. Regular surveys by this author in previous years covering the coast from the Olifants River to beyond Cape Frio have consistently shown this apparent barrier to fish distribution between Chamais Bay and the Lüderitz area (Cruickshank 1983b).

Chlorophyll values were low at the surface and at various depths throughout the region, except for one comparatively high point (15-16 at 0 m and 11 at 20 m) off Conception Bay. With this exception, the values for all parameters were average for the time of the year.

Phytoplankton densities are depicted in Figure 6. These values were obtained from settled volumes taken from N50V-net hauls. The phytoplankton distribution is bordered by a band of mixed (ratio: 7:3) zooplankton and phytoplankton. These two areas closely match the anchovy distribution, which suggests a correlation between fish and food supply.

DISCUSSION AND CONCLUSIONS

Although conditions were average for the time of year, three environmental features stand out in relation to anchovy distribution, namely, temperature, phytoplankton, and chlorophyll.

The two sets of histograms presented in Figures 2 and 4 show a predominance of smaller fish and larvae towards the north, with increased frequency of larger fish in the south. This has two implications:

i) that there is movement of larger length classes inshore and southward as the juveniles develop and grow to recruitment length;

ii) that anchovy larvae are concentrated offshore by some mechanism but that the post-larval fish move shorewards, as above.

This situation was compared with temperatures at the surface and at 25 m. In addition to the environmental barrier effect at 14 °C already discussed, there is also an offshore-inshore pattern of fish length classes from 14,0 to 17,0 °C. From this it can be inferred that anchovy juveniles favour more offshore, warmer waters above 15,5 °C during their larval and post-larval growth phase, whereas larger pre-recruits may prefer cooler, nearshore waters around 14,0 °C, where phytoplankton is more abundant.

The apparent paradox between the longshore temperature barrier and the offshore length distribution according to temperature suggests that the movement is not due solely to temperature and may also be motivated by food supply. This can be deduced from the close correspondence between phytoplankton and chlorophyll densities and fish distribution, which is in consonance with the data presented by Cruickshank (1983a) for surveys of fish distribution and environment plus analysis of catch distribution, which showed that anchovy predominate in the areas of highest phytoplankton abundance less than 20 n miles offshore. Taken together, these findings would appear to confirm King and MacLeod's (1976) findings that anchovy are phytofagous. However, in both the above cases the outer limits of anchovy distribution are characterized by a zoo- and phytoplankton mixture that favours zooplankton. Irregular data from catch samples also indicate that adult and juvenile anchovy stomachs can contain from 50-100 % zooplankton.

The origin of the larvae and post-larval recruits in the Orange River area is still open to speculation, but the data do give some indication as to the stock to which they are most likely to belong. Figures 2 and 4 show that the samples collected near Walvis Bay form part of a distinctly different length mode than do those much further south near the Orange River. Given this and the increasing evidence of a temperature barrier of cold water at least in the Lüderitz region (Boyd and Cruickshank 1983; Cruickshank 1983a and b), it is reasonable to assume that they belong to different stocks. Furthermore, a pattern of inshore movement with increased size fits the larval size distribution patterns found by Badenhorst and Boyd (1980), which led them to suggest a larval migration from Cape waters carried by the Agulhas and Benguela Currents.

The samples from Conception Bay were probably part of the drastically reduced recruitment stocks south of Walvis Bay, which in 1983 were too insignificant to make any contribution to the South West African fishery.

The data and conclusions presented herein confirm the suggestion made by Cruickshank (1979, Sea Fisheries Research Institute internal report) that the shoals off the Orange River area form an outlier of the St. Helena Bay stocks and that they move progressively southward with the advance of the winter months.

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to colleagues for fruitful discussions and to Mr. R. Cooper and his staff for technical assistance, particularly Messrs. D. Alexander, J. Fearon, C. Lubbe, and A. Busby, who did so much in the collection of the data during the survey, and to Capt. L. Swart and his crew on the R/S "BENGUELA" for their cooperation and help. Special thanks go to Dr. T. Hecht (Rhodes University) and Mr. A.J. Boyd (Sea Fisheries Research Institute) for their critical reading of the manuscript.

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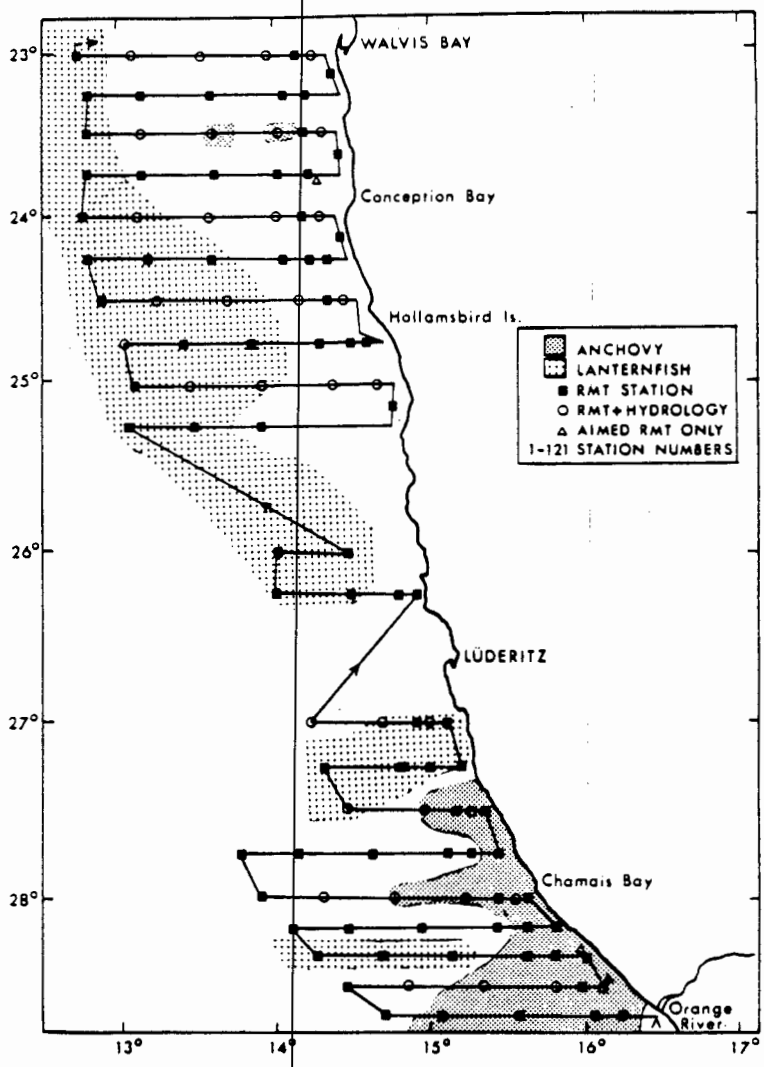

FIG. 1. Map of the grid sampled in the April 1983 hydroacoustic ecological and anchovy recruitment survey off South West Africa (RMT = rectangular midwater trawl)

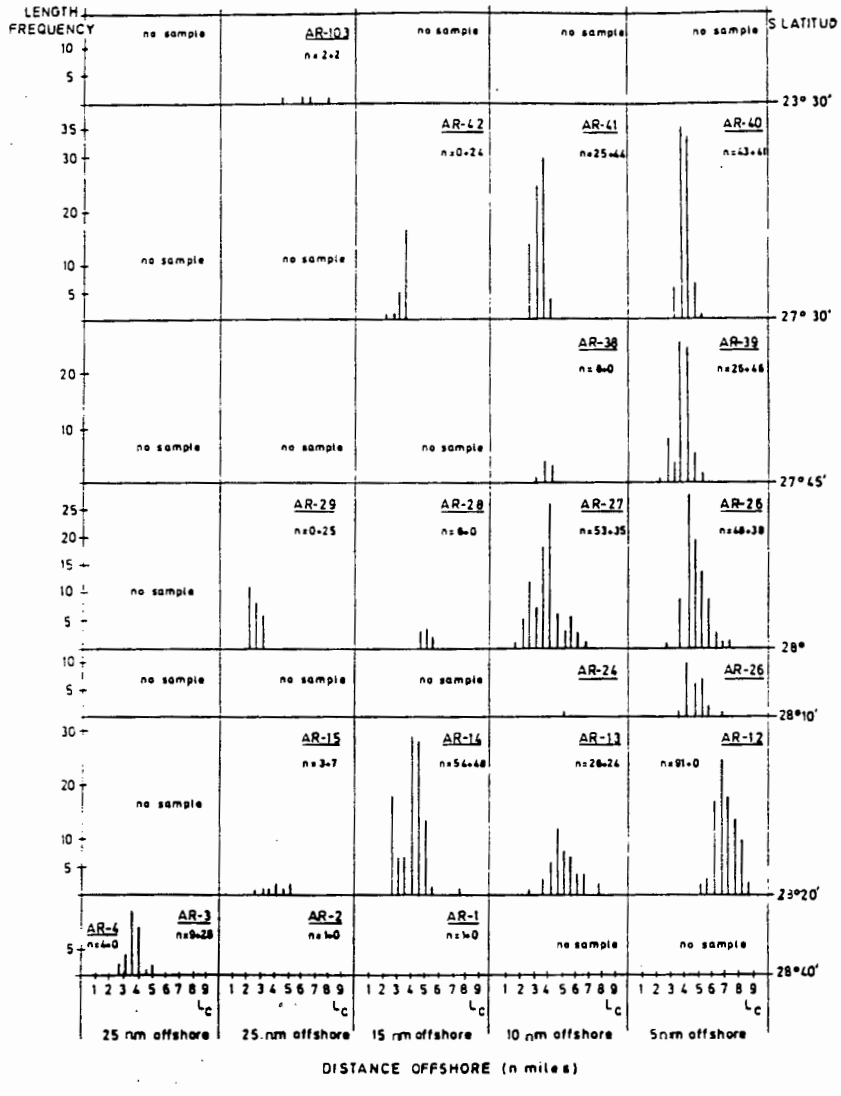

FIG. 2. Length frequencies of juvenile anchovy by station against latitude

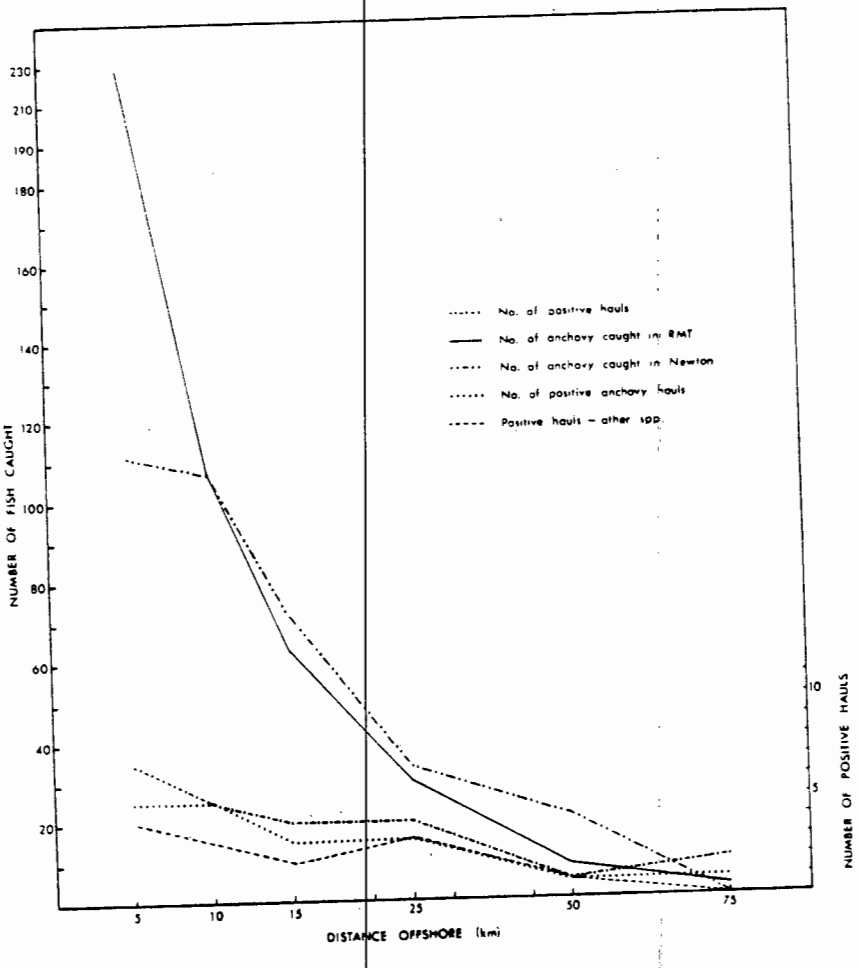

FIG. 3. Catch distribution according to distance offshore

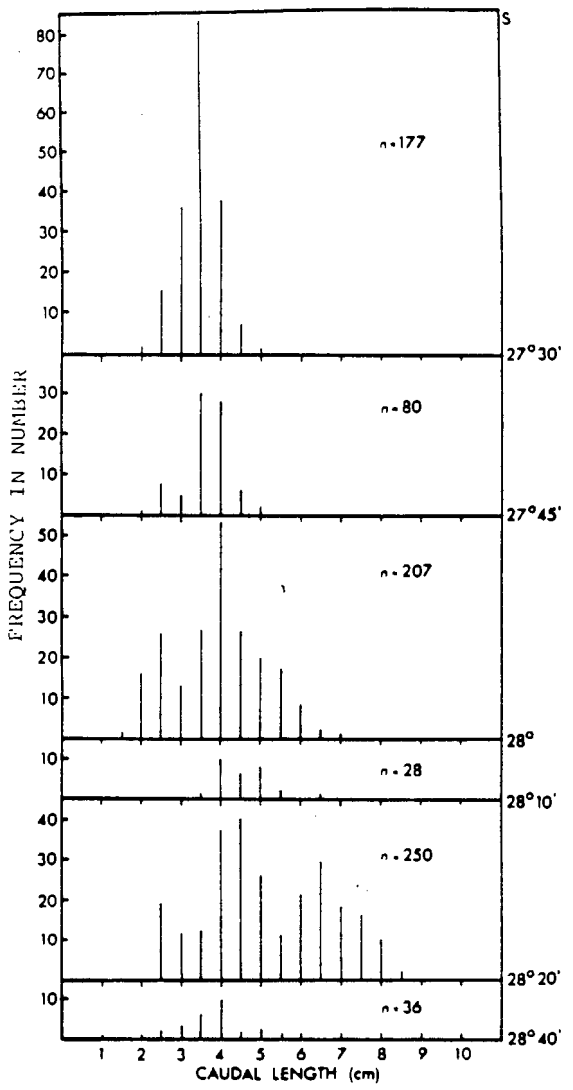

FIG. 4. Length frequency by degree of latitude

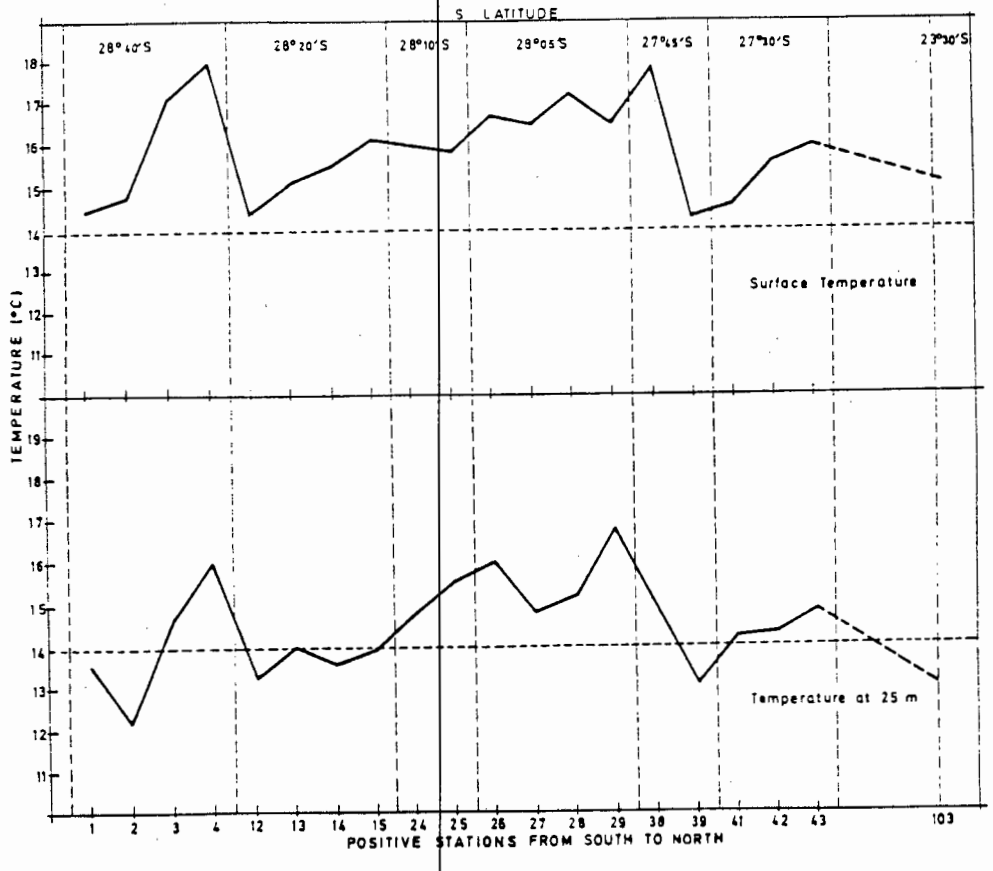

FIG. 5. Temperatures at positive anchovy stations

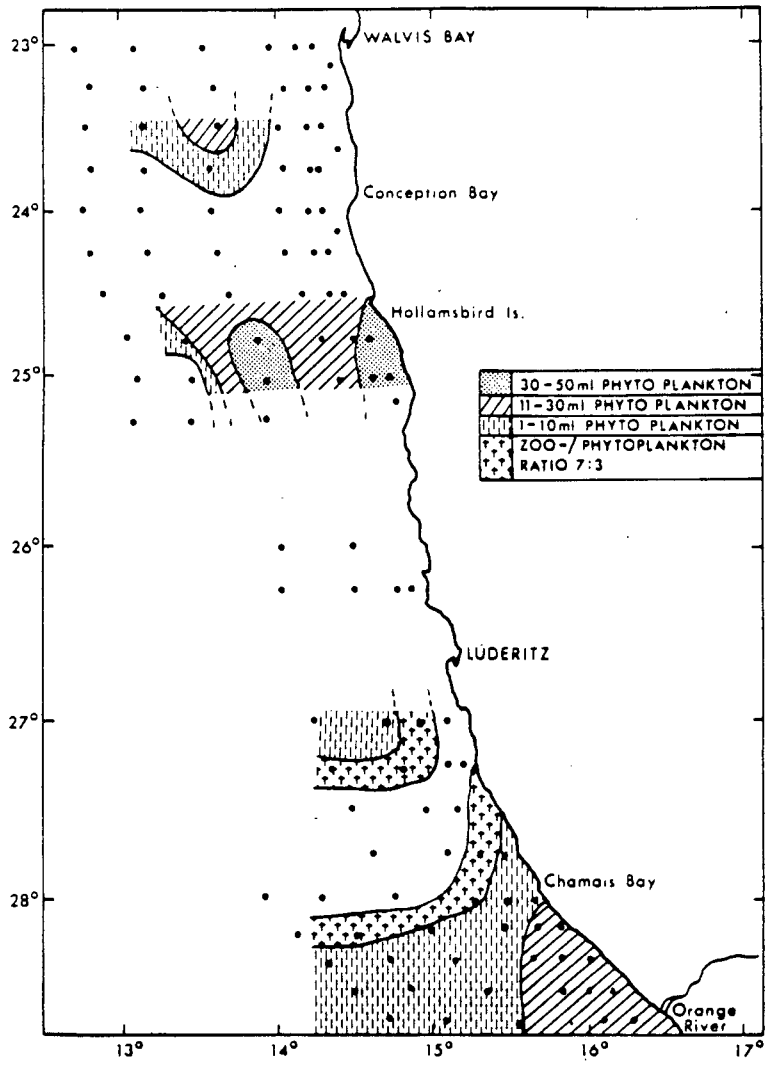

FIG. 6. Phytoplankton densities in the survey area

Fish. Bull. S. Afr. 16:99–114
1982

ENVIRONMENTAL ASPECTS OF A FEW PELAGIC FISH SHOALS OFF SOUTH WEST AFRICA

I. KRUGER AND R.A. CRUICKSHANK

Limited ecological studies of fish shoals were carried out off South West Africa during June 1973 and April 1974. The feeding habits of the fish are discussed in terms of the available food organisms, stomach content weights relative to maturity stage and the location of the fish in relation to phytoplankton concentrations in the environment. The degree to which the abiotic environment (wind, temperature, salinity and oxygen concentration) affects the behaviour of the fish shoals is also discussed.

Gedurende Junie 1973 en April 1974 is beperkte ekologiese studies oor visskole langs die kus van Suidwes-Afrika uitgevoer. Die voedingsgewoontes van die vis word bespreek na aanleiding van die beskikbare voedselorganismes, pensinhoudgewigte relatief tot rypheidstadia en die ligging van die vis ten opsigte van die fitoplanktonkonsentrasie in die omgewing. Die mate waarin die abiotiese omgewingstoestande (wind, temperatuur, soutgehalte en suurstofkonsentrasie) die gedrag van die visskole beïnvloed, word ook bespreek.

A study of the biology and population dynamics of pelagic fish species in relation to their immediate biotic and abiotic environment is useful, in that such information on fish shoal ecology can be used to assist in rational management of the fisheries. Andrews (1974) also stressed the need to understand the relationship between each fish species and its environment in order to ensure proper fisheries management.

Investigations of fish shoal ecology were conducted during the Cape Cross Programme, a multidisciplinary research programme in the area between 17°S and 24°40'S. It was carried out during the period 1970—1974, with the major aim of investigating the decline of the pilchard *Sardinops ocellata* stock following peak landings in 1968. The present report deals with pilchard and anchovy *Engraulis capensis* shoals, their feeding and aspects of their immediate environment, all of which were studied during June 1973 and April 1974. The observations are discussed in the light of the findings of other workers in this field.

BACKGROUND

A synopsis of the feeding of the South West African pilchard was given by Matthews (1960) with short notes on the environmental conditions. More detailed feeding studies on pilchard and anchovy were conducted by Macleod (1972), King (1973) and King and Macleod (1976). Davies (1957) made a fairly detailed study of the feeding of the South African pilchard off the west coast of South Africa, and a synopsis of its feeding and ecology was given by De Jager (1959). Stander (1964), Du Plessis (1967) and O'Toole (1980) have detailed the patterns of the hydrological regime of South West African waters. Kruger (1972), De Vos and Visser (1972), Visser *et al.* (1973) and Wessels *et al.* (1974) discussed the relationship between pelagic fish and their environment off South West Africa. Agenbag (1980) reported on the distribution of pelagic fish as influenced by hydrology. He earlier investigated vertical migration of pelagic fish shoals and the influence of the moon on them (Agenbag 1973). This report covers the results of two brief sampling cruises in 1973 and 1974. Limited biological data are looked at in relation to hydrological parameters and to phytoplankton availability for three anchovy and eight pilchard shoals.

MATERIAL AND METHODS

Shoal detection and sampling

Scientific observations were made of eight shoals in June 1973 (winter) and three shoals in April 1974 (autumn). In a co-operative effort between six commercial boats and two research vessels of the Sea Fisheries Institute, sample catches were made of the eight shoals in June. Shoals 9—11 were studied in April 1974 from two of the Institute's research vessels and a chartered aircraft. Hydrological and acoustic data were recorded and samples of the fish and the plankton were collected. Subsamples of 25 fish were taken from each of the catches made during the June survey after bulk sample analysis (for length frequencies) had been completed. No fish samples were collected from Shoals 9—11 because no catcher vessel was employed.

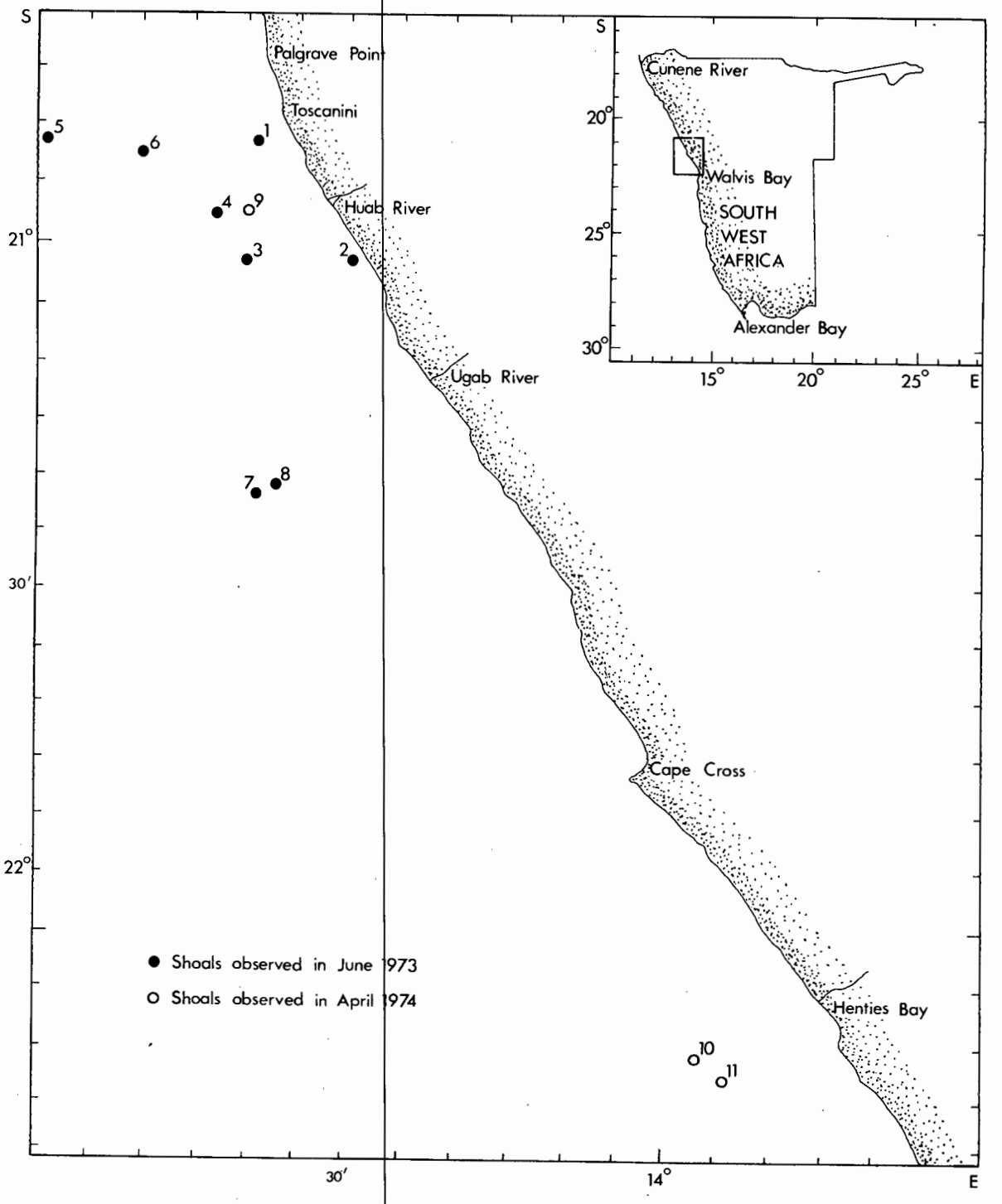

Fig. 1: Positions of shoals

Environmental sampling

A Nansen-Pettersson bottle was used to collect samples for salinity and oxygen determination and to record the temperature at various depths.

In June 1973, the bottle samples also served for quantitative phytoplankton analysis. In April 1974, at Shoals 9—11, the phytoplankton was only qualitatively sampled by means of closing-net hauls.

Wind data were recorded from a ship-borne anemometer.

Biological analysis

Quantitative and qualitative phytoplankton samples were analysed according to the methods used by Nel (1968). Phytoplankters were identified to species level (Appendix), counted and the percentage composition of the most important groups calculated. The small quantities of zooplankton collected were not analysed.

Average fresh weight (mass) of stomach contents, frequency of maturity stage per subsample and overall mean weight of stomach contents per maturity stage were determined for anchovy and pilchard. The maturity stages are as described by Davies (1956).

SHOAL PARAMETERS

Shoal positions

Shoal positions are plotted on Figure 1. Shoals 1, 6 and 5 were respectively 7, 29 and 44 km off Toscanini. Shoals 9 and 4 were 16 and 22 km off the Huab River, whereas Shoals 2 and 3 were south of the river, 4 and 22 km off shore. South of the Ugab River, shoals 7, 8, 10 and 11 were respectively 44, 40, 27 and 24 km off shore.

Shoal identification

The species composition of Shoals 1—8 was determined from purse-seine catches. Shoals 9—11 were located by chartered aircraft, and Shoals 10 and 11 were identified by their characteristic shoal form. Shoal 9 was not identified because of poor visibility. The identities of the shoals are listed in Table I.

Shoal depth and thickness

The maximum depth of all shoals caught in June 1973 (except Shoal 2) was 30 — 40 m below the surface, but in April 1974, no part of any shoal was deeper than 12 m (Table I). The upper limits of the June shoals were 2—27 m deep, and those of the April shoals 0—4 m. Vertical thickness of winter shoals was greater than 18 m in five instances and 5 m or less in three. Autumn shoals were all between 5 and 11 m thick.

Maturity and feeding

Subsamples totalling 200 fish were measured for length, and the sex, stomach weight and maturity stages were determined. All fish were adult. Anchovy lengths (L_c) ranged from 102 to 154 mm (75 fish) and pilchard from 194 to 256 mm (125 fish).

Average stomach weights per subsample of the three anchovy and five pilchard shoals are given in

Table I: Fish shoals sampled in June 1973 and April 1974

Shoal number	Species	Date sampled	Time caught	Mass caught (metric tons)	Sounding (m)	Shoal depth (m)
1	Anchovy	14.6.73	09h10	1,0	35	27-30
2	Anchovy	15.6.73	06h10	0,1	15	6-10
3	Anchovy	15.6.73	19h04	3,6	96	2-30
4	Pilchard	15.6.73	20h00	44,8	100	8-36
5	Pilchard	16.6.73	14h30	49,9	120	25-30
6	Pilchard	16.6.73	15h00	51,1	113	18-36
7	Pilchard	17.6.73	12h05	36,7	115	13-40
8	Pilchard	17.6.73	13h33	88,2	113	11-36
9	Not identified	22.4.74	05h00*	None	76	0-11
10	Pilchard	23.4.74	22h15*	None	71	0-5
11	Pilchard	23.4.74	23h30*	None	66	4-12

* Time observed on echo sounder

Table II: Stomach weight and maturity of fish in each shoal

Date	Shoal number	Species	Time caught	Average stomach weight (g) per subsample of 25 fish	Maturity (percentage of each subsample of 25 fish)		
					Inactive	Active	Spent/spent-inactive
14.6.73	1	Anchovy	09h10	0,084	72	8	20
15.6.73	2	Anchovy	06h10	0,056	64	4	32
15.6.73	3	Anchovy	19h04	0,248	16	4	80
15.6.73	4	Pilchard	20h00	0,264	12	76	12
16.6.73	5	Pilchard	14h30	0,192	8	48	44
17.6.73	6	Pilchard	15h00	0,140	12	48	44
17.6.73	7	Pilchard	12h05	0,176	20	72	8
17.6.73	8	Pilchard	13h33	0,228	8	79	13

Total for all subsampled fish

Inactive				Active				Spent/spent-inactive			
Number of fish		Average stomach weight (g)		Number of fish		Average stomach weight (g)		Number of fish		Average stomach weight (g)	
Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard
38	15	0,068	0,133	4	80	0,100	0,209	33	30	0,200	0,210

Table II. In addition, the overall mean stomach weights for the sexual stages inactive, active and spent/spent-inactive were calculated from the 75 anchovy and 125 pilchard. These stomach weights were tested statistically against time caught and the three maturity groups mentioned above for both species. The data are too few for valid statistical analysis, but statistical tests (Anovar or *t*-test) were applied to check the strength of the trends suggested.

The mean stomach weight of the anchovy caught in the evening was significantly higher at the 5-per-cent level (Anovar test: $F_s = 36,1$; df = 2 and 72) than those caught in the morning. Overall mean stomach weight of the maturity group spent/spent-inactive for anchovy caught in the evening was significantly higher at the 5-per-cent level (Anovar test: $F_s = 14,09$; df = 2 and 72) than that of inactive and active fish. Eighty per cent of the anchovy Shoal 3, caught at 19h00, were spent/spent-inactive, whereas Shoals 1 and 2 caught in the morning and at dawn respectively, consisted of nearly 70 per cent fish in the inactive stage. In all three shoals, only about 5 per cent were active.

The stomach weights of pilchard caught from midday to evening did not significantly differ (Anovar test: $F_s = 1,58$; df = 4 and 120). Also, no significant difference in stomach weights of the three maturity groups was found (Anovar test: $F_s = 1,03$; df = 2 and 122). Almost 76 per cent of the fish in Shoals 4, 7 and 8 were in the active condition, 13 per cent were inactive and 11 per cent spent/spent-inactive. Shoals 5 and 6 contained 46 per cent active fish, 44 per cent spent/spent-inactive and 10 per cent inactive (Table II). Shoals 5 and 6 were caught in mid-afternoon, Shoals 7 and 8 at midday and Shoal 4 after sunset. The difference in mean stomach weight of Shoals 4, 7, 8 and Shoals 5 and 6 was statistically significant in a *t*-test only at the 10-per-cent level.

Vertical migration of shoals

The depths of shoals sampled are considered here to be representative of their activity in the cycle of circadian vertical migration (Fig. 2). However, it must be cautioned that the shoals were sampled in three discrete areas and at different times. Shoals 1 — 6 were sampled from the same area on three successive days, but they were not serially sampled from dawn, through daylight and into the night. The migration pattern was therefore not actually observed (directly), but it was assumed from sample data and the corresponding findings of other authors.

BIOLOGICAL ENVIRONMENT

Phytoplankton at fish shoal positions

The percentage composition of phytoplankton present at each fish shoal position is given in Table III. Only the most important diatom species and other notable groups found are presented in Table

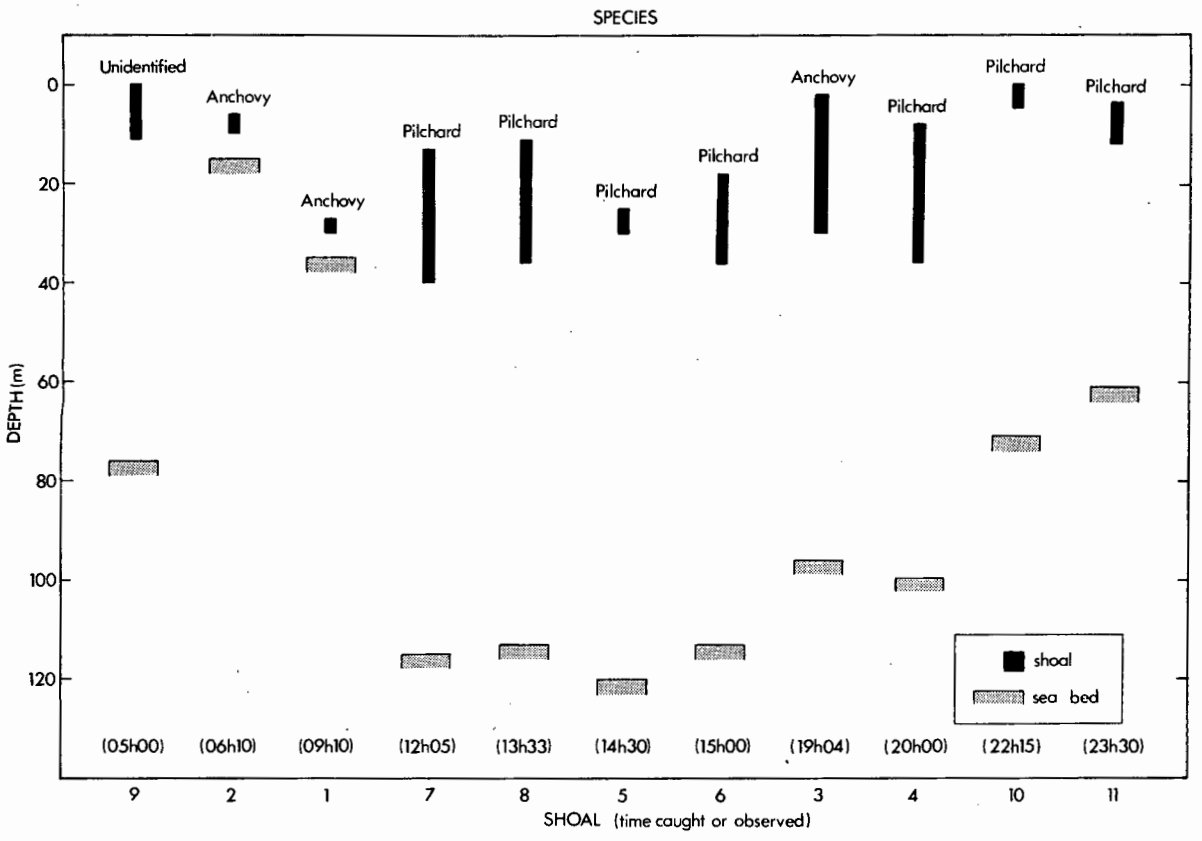

Fig. 2: Distribution of pelagic fish shoals by depth and time of day

III. The total list of species present in samples is given by taxonomic group in the Appendix.

Other than in the vicinity of Shoal 5, phytoplankton density at the surface ranged between 833×10^3 and 1788×10^3 cells $\cdot \ell^{-1}$. At shoal 5, it was only 158×10^3 cells $\cdot \ell^{-1}$. In comparison, the densities at shoal

Table III: Phytoplankton composition at fish shoal positions

Phytoplankton taxon	Composition of phytoplankton at each shoal position (%)											
	1	2	3	4	5	6	7	8	9	10	11	Total
DIATOMS												
Thalassiosira decipiens	24,1	12,1	55,9	66,8	82,0	59,3	51,5	46,1	8,9	29,0	27,9	42,1
Delphineis karstenii	60,5	74,6	17,7	6,6	5,1	6,5	0,8	—	46,2	10,8	3,1	21,1
Chaetoceros spp.	2,5	3,7	10,4	7,8	0,7	4,1	21,2	31,4	19,4	20,7	27,4	13,6
Asterionella japonica	3,0	2,0	8,6	10,2	4,0	4,7	1,5	2,8	20,8	0,7	0,7	5,4
Nitzschia spp.	2,5	1,6	2,9	3,6	2,4	3,3	6,4	4,7	1,0	3,0	5,2	3,3
Bacteriastrum delicatulum	—	—	—	—	—	—	8,1	6,5	—	—	—	1,3
Rest of diatoms	2,5	3,5	2,0	2,9	4,8	4,9	9,3	7,8	3,0	18,8	14,4	6,7
OTHER GROUPS												
Dinoflagellates	0,3	0,3	0,6	1,2	0,2	1,2	0,1	0,4	0,8	16,1	20,3	3,8
Blue green algae	3,0	2,5	—	—	—	15,6	—	—	—	0,2	0,3	1,9
Flagellates (unknown)	1,2	—	1,6	—	0,2	0,1	0,5	0,1	—	—	0,4	0,4
Rest of other groups	0,4	0,2	0,4	0,6	0,1	0,5	0,2	0,3	0,1	0,7	0,6	0,4

Table IV: Environmental data at shoal sampling stations, June 1973

Shoal number	Shoal depth range (m)	Sampling depths (m)	Temperature (°C)	Salinity (‰)	Oxygen concentration (mℓ/ℓ⁻¹)	Phytoplankton abundance (cells·ℓ⁻¹)	Wind	
							Speed (knots)	Direction
1	27-30	0	13,60	35,23	3,18	1 312 500	20	SSE
		5	13,60	35,23	2,83	1 840 000		
		10	13,57	35,22	2,83	625 000		
		25	13,21	35,21	1,27	369 500		
2	6-10	0	13,60	35,27	2,85	1 620 000	7	SSE
		5	13,47	35,26	2,15	2 222 000		
		10	13,22	35,25	1,25	1 962 500		
3	2-30	0	13,97	35,28	4,52	832 500	10	SSE
		5	13,93	35,27	4,26	790 000		
		10	13,90	35,27	4,26	522 500		
		20	13,65	35,27	3,42	882 500		
		30	13,51	35,26	2,19	1 682 500		
		50	13,14	35,25	0,85	360 000		
		75	12,71	35,23	0,13	37 500		
4	8-36	0	13,90	35,26	4,53	930 000	9	SSE
		5	13,89	35,20	4,47	665 500		
		10	13,82	35,26	4,17	780 000		
		20	13,70	35,24	3,70	742 500		
		30	13,60	35,27	2,84	637 500		
		50	13,21	35,25	0,83	290 000		
5	25-30	0	14,12	35,28	4,91	157 500	13	S
		5	14,10	35,25	4,93	1 512 500		
		10	14,07	35,27	4,84	1 372 500		
		20	14,05	35,29	4,84	1 202 500		
		30	14,03	35,21	4,82	1 017 500		
		50	13,74	35,23	2,41	777 500		
		75	12,59	35,17	0,78	25 000		
		115	12,04	35,12	0,50	25 000		
6	18-36	0	14,15	35,24	4,80	855 000	15	S
		10	13,86	35,21	4,63	1 067 500		
		20	13,78	35,23	3,91	845 000		
		30	13,60	35,25	3,47	750 000		
		50	13,02	35,22	0,81	665 000		
		110	12,12	35,12	0,25	265 000		
7	13-40	0	14,51	35,25	4,51	1 172 500	15	ESE
		10	14,40	35,24	4,52	939 500		
		20	14,37	35,30	4,58	997 500		
		30	14,21	35,26	3,82	657 500		
		40	13,69	35,25	1,91	675 000		
		75	12,70	35,20	0,49	197 500		
		110	12,18	35,13	0,15	17 500		
8	11-36	0	14,41	35,24	4,85	1 787 500	16	ESE
		10	14,38	35,30	4,72	2 515 000		
		20	14,25	35,28	3,99	1 540 000		
		30	13,75	35,27	2,15	895 000		
		40	13,47	35,29	1,31	635 000		
		75	12,65	35,21	0,27	102 500		
		110	12,22	35,15	0,09	67 500		

Table V: Environmental data at shoal sampling stations, April 1974

Shoal number	Shoal depth range (m)	Hydrological sampling depths (m)	Temperature (°C)	Salinity (‰)	Oxygen ($m\ell \cdot \ell^{-1}$)	Phytoplankton sampling depths (m)	Phytoplankton abundance (cells·haul·m^{-1})	Wind	
								Speed (knots)	Direction
9	0-11	0	16,46	35,47	3,23			<1	Calm
		5	16,42	35,46	3,38	0-11	168,72		
		11	16,44	35,48	3,22				
		20	16,36	35,50	3,26	11-50	160,15		
		30	16,30	35,47	2,91				
		50	16,08	35,47	2,17	50-70	50,25		
		70	15,80	35,52	0,62				
10	0-5	0	17,62	35,11	5,33	0-5	3,64	10	SSW
		10	16,79	35,31	4,43				
		20	15,56	35,33	0,85	5-50	32,90		
		30	14,95	35,38	0,11				
		50	14,72	35,37	0,10	50-65	2,81		
		65	14,69	35,38	0,10				
11	4-12	0	17,13	35,27	5,30			10	S
		4	17,04	35,19	4,74	0-4	5,45		
		8	16,92	35,27	4,98	4-12	3,72		
		12	16,86	35,27	4,50				
		20	16,47	35,28	3,47	12-50	8,50		
		30	15,24	35,35	0,30				
		50	14,74	35,38	0,12				
						50-60	3,43		

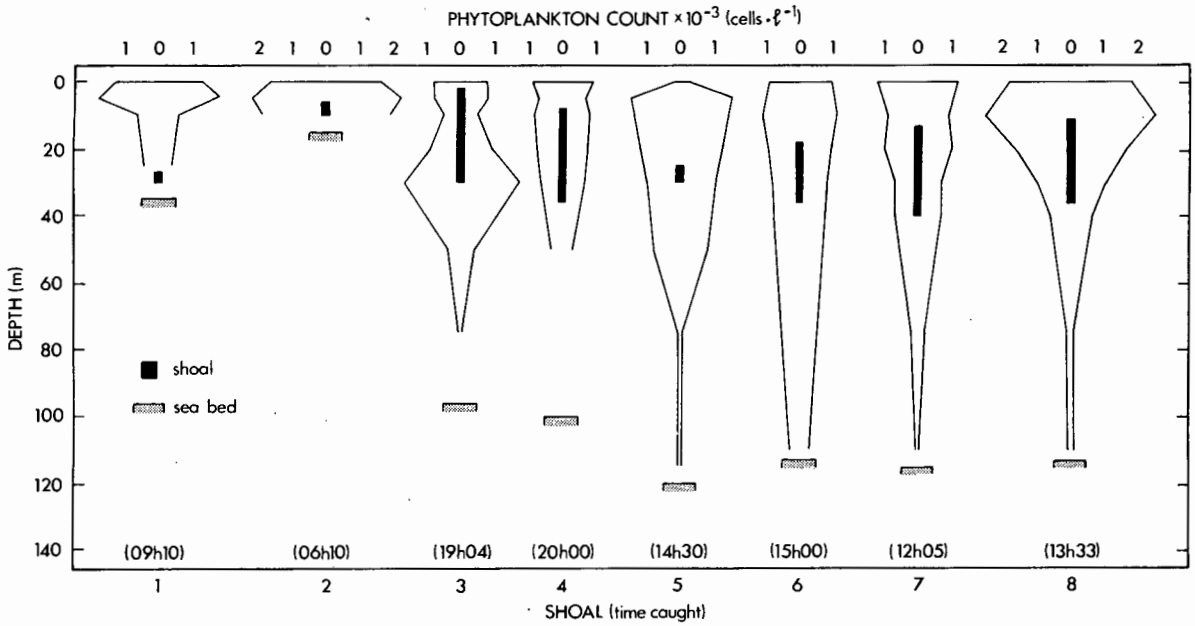

Fig. 3: Vertical distribution of phytoplankton and pelagic fish shoals, June 1973

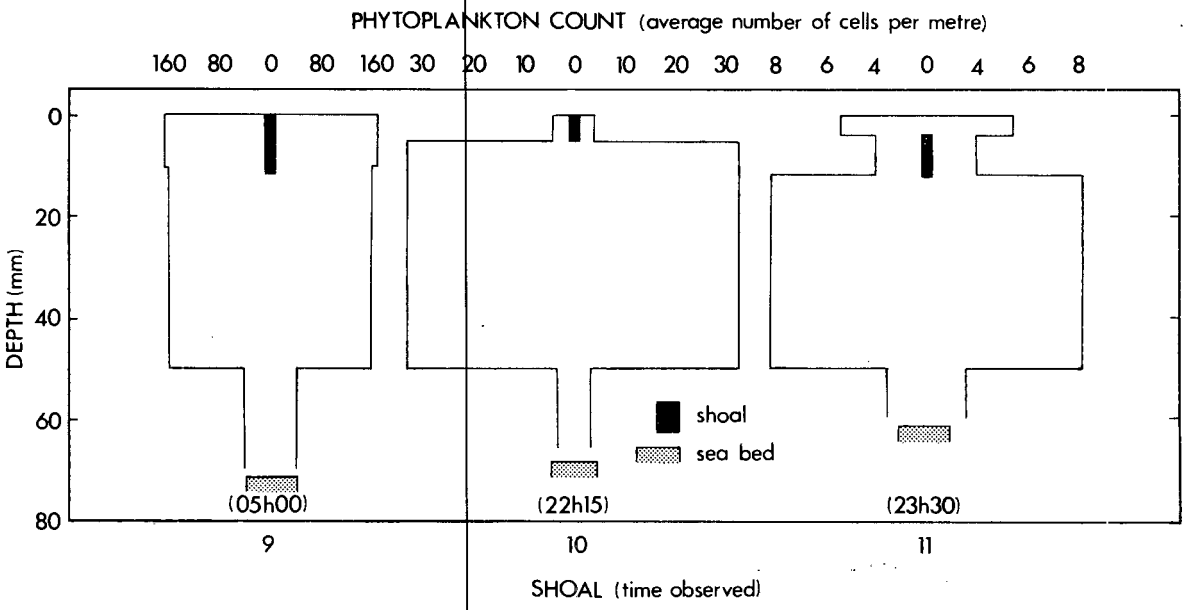

Fig. 4: Vertical distribution of phytoplankton and pelagic fish shoals, April 1974

depths (upper and lower limits) showed greater variation, ranging from 300×10^3 to $2\,500 \times 10^3$ cells·ℓ^{-1} (Tables IV and V).

Vertical distribution of phytoplankton

Phytoplankton concentrations compared to depth are recorded in Tables IV and V and plotted with shoal depth in Figures 3 and 4. The phytoplankton concentrations at Shoals 9 — 11 are not quantitative for individual depths because they were obtained from closing-net hauls. They are therefore not statistically comparable with the concentrations obtained quantitatively for Shoals 1 — 8.

Maximum phytoplankton standing crop was most often at 5—10 m, but at Shoals 3, 5 and 8 it was as deep as 30 m. At Shoals 4, 7 and 9 the surface

Table VI: Upper and lower limits of physical and biological parameters of fish shoals

Shoal number	Sounding (m)	Range				
		Shoal depth (m)	Temperature (°C)	Salinity (‰)	Oxygen (m$\ell \cdot \ell^{-1}$)	Phytoplankton (cells·ℓ^{-1})
1	35	27-30	—	—	—	—
2	15	6-10	13,22-13,42	35,25-35,26	1,25-1,97	1 963 - 2 169 x 10^{-3}
3	96	2-30	13,51-13,95	35,26-35,28	2,19-4,42	816 - 1 683 x 10^{-3}
4	100	8-36	13,49-13,85	35,24-35,26	2,23-4,29	533 - 734 x 10^{-3}
5	120	25-30	14,03-14,04	35,21-35,25	4,82-4,83	1 018 - 1 110 x 10^{-3}
6	113	18-36	13,43-13,80	35,23-35,24	2,69-4,05	725 - 890 x 10^{-3}
7	115	13-40	13,69-14,39	35,25-35,26	1,91-4,54	675 - 957 x 10^{-3}
8	113	11-36	13,58-14,37	35,28-35,30	1,67-4,65	739 - 2 418 x 10^{-3}
9	76	0-11	16,44-16,46	35,47-35,48	3,22-3,23	*
10	71	0-5	17,22-17,62	35,11-35,21	4,88-5,33	*
11	66	4-12	16,86-17,04	35,19-35,27	4,50-4,74	*

— Environmental data not taken to shoal depth
* Qualitative data incomparable

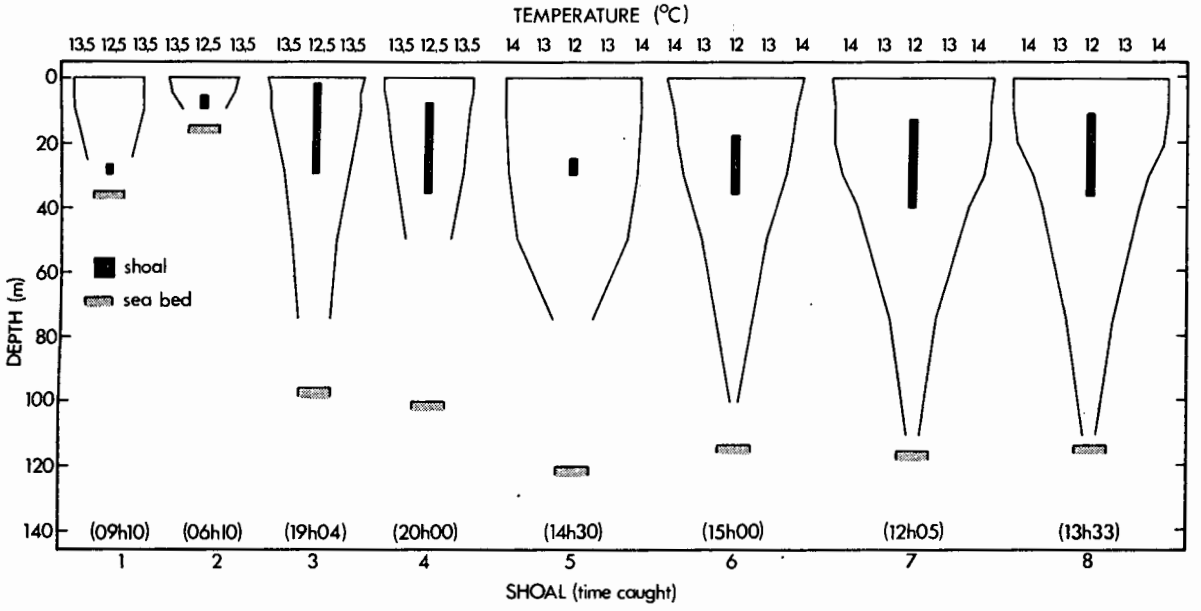

Fig. 5: Vertical distribution of temperature and pelagic fish shoals, June 1973

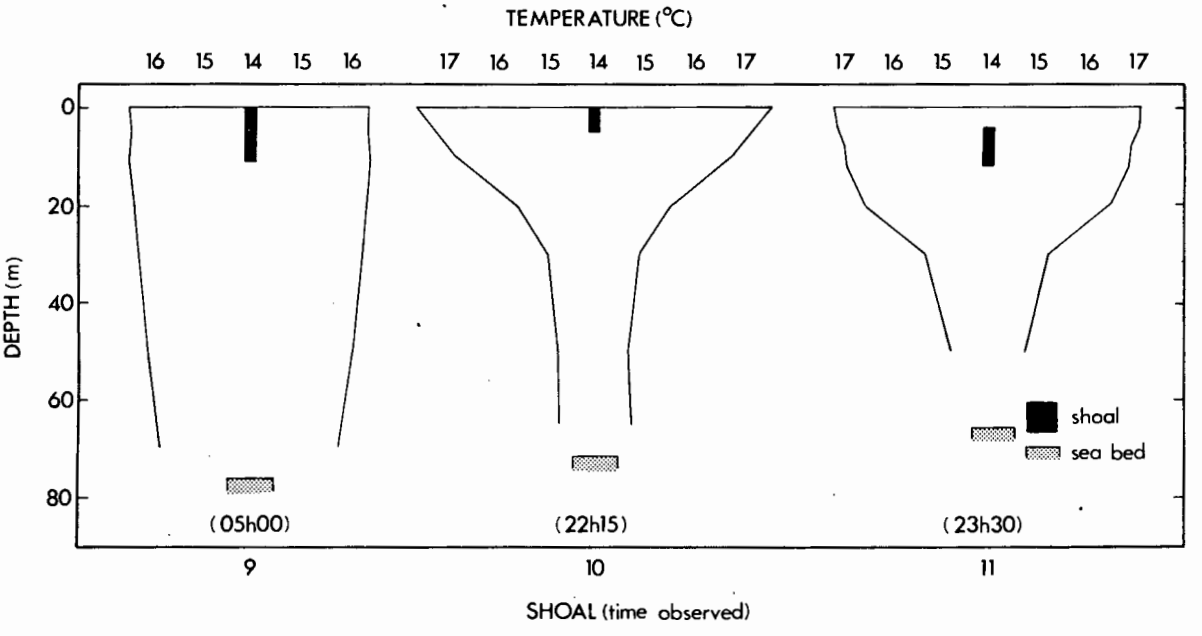

Fig. 6: Vertical distribution of temperature and pelagic fish shoals, April 1974

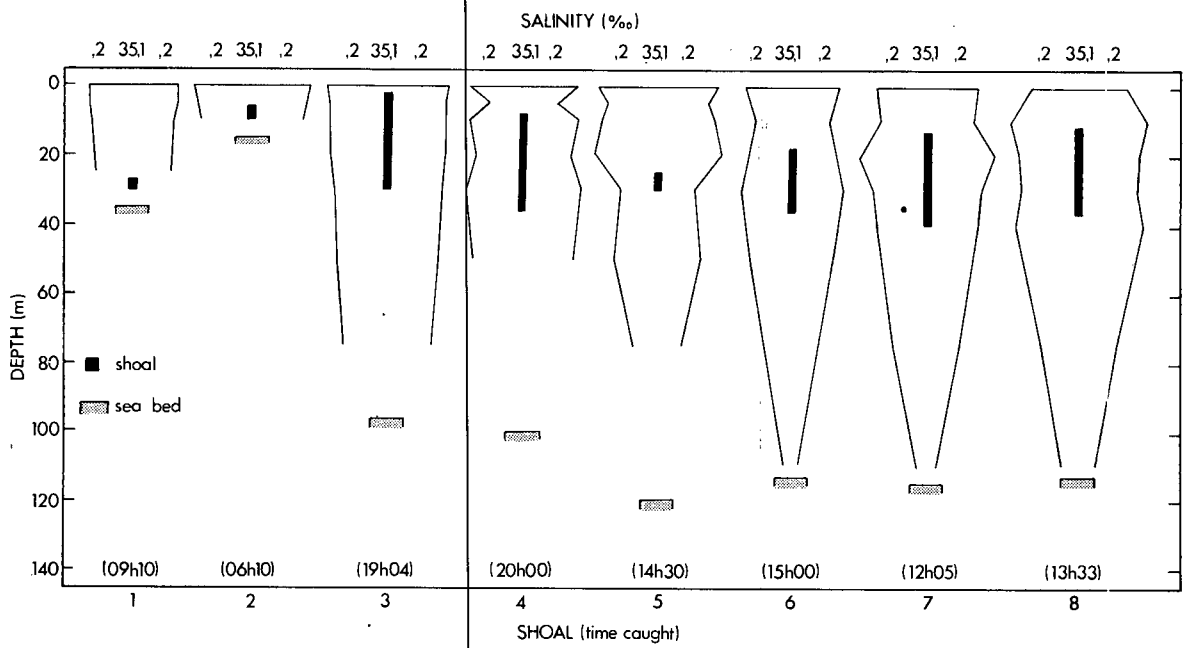

Fig. 7: Vertical distribution of salinity and pelagic fish shoals, June 1973

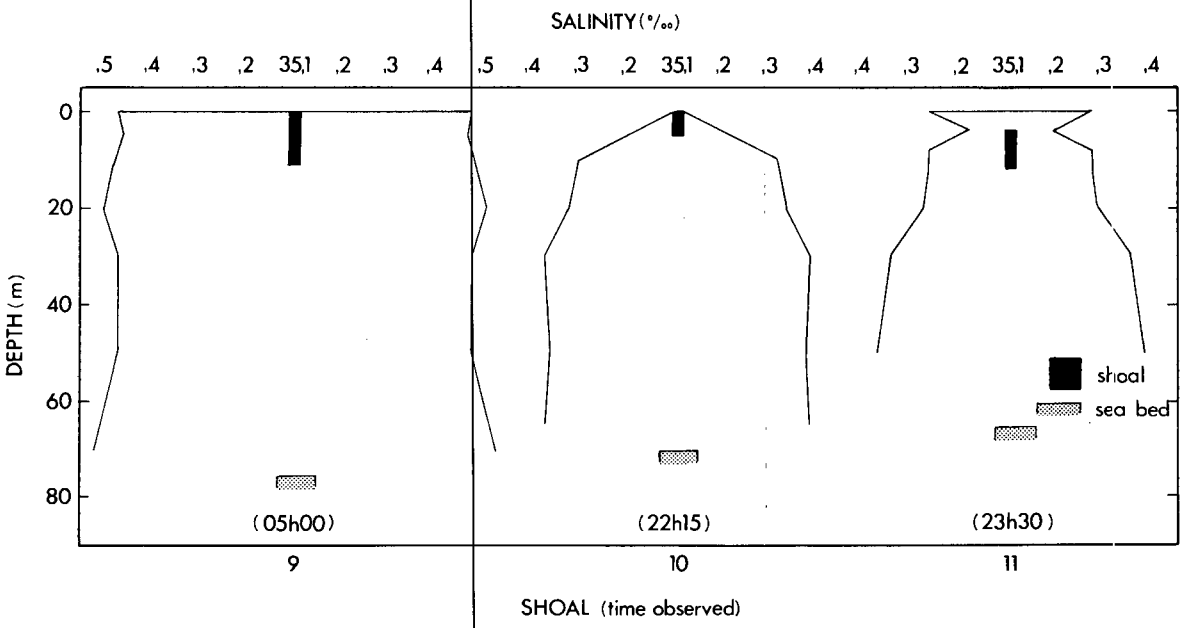

Fig. 8: Vertical distribution of salinity and pelagic fish shoals, April 1974

concentration was also the maximum.

PHYSICAL ENVIRONMENT

Temperature

Surface and subsurface temperatures of Shoals 1—8 (winter) were 2—4°C lower than those of autumn shoals (9—11)—Tables IV, V and VI. Surface temperature for both groups of shoals fluctuated within one degree, 13,60—14,51°C for the winter group and 16,46—17,62°C for the autumn group. Subsurface temperatures at the upper limits of Shoals 1—8 were not more than 0,5°C lower than at the surface and were the same as the surface temperatures associated with Shoals 9—11. Temperature differences between upper and lower limits of all shoals were slight, never being more than 0,8°C at any shoal (Table VI). Changes of temperature per metre of shoal depth at any shoal were not more than 0,1°C, suggesting that no sharp temperature gradients were endured by the fish.

The relationship between the fish shoals and the vertical distribution of temperature is presented graphically in Figures 5 (June 1973) and 6 (April 1974). The lack of any strong thermocline in either autumn or winter is clear. Where there is even a very weak thermocline present, as at Shoals 10 and 11, the fish kept well above it whereas, if lacking, the shoals extended deeper.

Salinity

The salinities associated with winter and autumn shoals are presented in Tables IV and V.

No relationship between the fish shoals and the surface and vertical distribution of salinities were found as can be seen on Figures 7 (June 1973) and 8 (April 1974).

Oxygen

Surface dissolved-oxygen concentrations close to the coast at winter Shoals 1 and 2 and autumn Shoal 9 were lower than for Shoals 3—8 further off shore near Palgrave Point in the north, but were highest for autumn shoals 10 and 11 off Henties Bay in the south (Tables IV and V).

Subsurface oxygen concentrations in shallow water at the small nearshore shoals (1 and 2) were low, varying between 1,25 and 1,97 $m\ell \cdot \ell^{-1}$. For most other winter shoals in deeper water, oxygen concentration varied between 1,67 and 4,83 $m\ell \cdot \ell^{-1}$ (Tables IV and V). Dissolved oxygen concentration at the shoal depths was reasonably constant for the autumn (1974) shoals and for Shoal 5 (winter 1973), varying by as little as 0,01 $m\ell \cdot \ell^{-1}$ and by a maximum of 0,5 $m\ell \cdot \ell^{-1}$.

The relationship between the fish shoals and the vertical distribution of oxygen is presented graphically in Figures 9 (June 1973) and 10 (April 1974). As might be expected, dissolved oxygen concentrations decrease more gradually where no notable thermocline is present, but decrease rapidly with even the weak thermoclines of Shoals 10 and 11. These two shoals clearly occurred well above the oxyclines. Also, the minimum dissolved oxygen available to the shoals was 2,2 $m\ell \cdot \ell^{-1}$ except at Shoals 7 and 8, where the lowest concentrations were 1,9 and 1,3 $m\ell \cdot \ell^{-1}$ respectively.

Wind

Wind speed and direction are reflected in Tables IV and V. The prevalent winds were from south to east-south-east except at Shoal 10, where the wind blew from south-south-west. Wind speeds were low to moderate in the range of 7—17 knots, except at Shoal 1 where winds reached 20 knots, and at Shoal 9 where it was calm. Therefore, it is unlikely that hydrological conditions were in the process of rapid change as a result of the prevalent winds.

DISCUSSION

Agenbag (1980), in his investigation of the general distribution of pelagic fish off South West Africa, designated a winter (i.e. April—September) and a summer (i.e. October—March) distribution pattern. During winter, he found a greater frequency of shoals 18,5 km or more from the shore, whereas in summer they appeared more frequently closer to the coast. He concluded that the winter distribution was influenced by temperature and dissolved oxygen. During this survey, which was carried out in the same years and coincided with Agenbag's winter period, the off-shore distribution of the shoals conforms to his winter distribution. Shoals 1 and 2 do not conform because they were close to the coast.

The stomach weights of fish sampled, when compared with the relationship between shoal depths and phytoplankton abundances at depth presented in Figures 3 and 4, appear to indicate that both

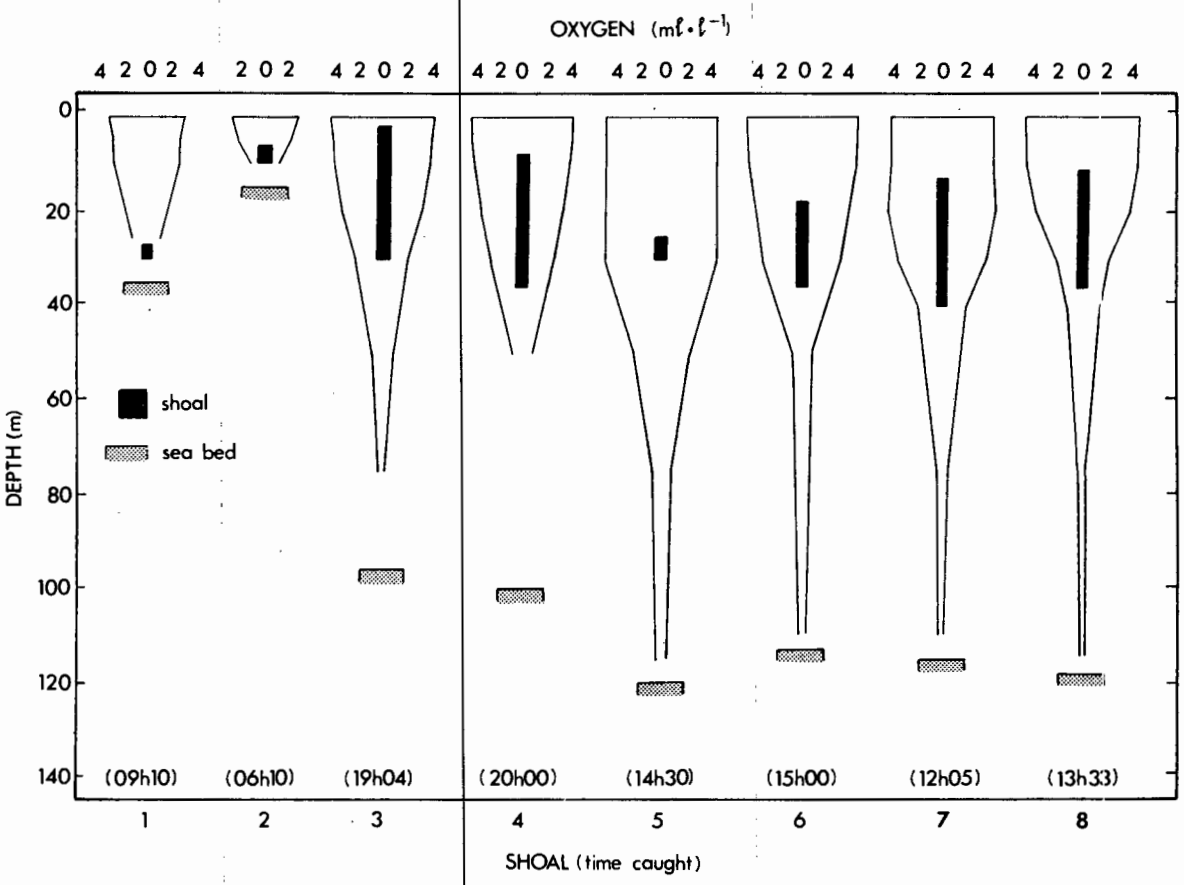

Fig. 9: Vertical distribution of oxygen concentration and pelagic fish shoals, June 1973

anchovy and pilchard feed during the day and night. However, stomach fullness and weights for anchovy were significantly higher at sunset than at dawn or early in the morning. This suggests that anchovy do more feeding in the late afternoon and evening than they do after midnight. Pilchard may follow a similar trend. Their stomach weights showed no significant difference whether caught at midday, mid-afternoon or after sunset, but because no shoals were caught in the early morning, no comparison with anchovy feeding patterns can be made here. Davies (1957) found no distinct trend of pilchard favouring night or day feeding, but his sampling was from commercial catches which were heavily biased to the night hours. According to Yoneda and Yoshida (1955), the closely related species *Sardinops melanosticta* feeds mainly during the day, but shows greater stomach weight at night off the Kyoto coast in Japanese waters.

The significant difference in stomach weight of anchovy in the spent/spent-inactive stage compared to those in active or inactive condition points towards greater feeding activity after spawning than in the pre-spawning stages. Such an increase in feeding may be to counteract the physiological drain of spawning. Pilchards did not show a highly significant difference over the three maturity stages, although Matthews (1960) stated that pilchard stop feeding at least for a short period during spawning. The results do show concentrated feeding activity by shoals with 76 per cent of their fish in the active condition around midday and after sunset, whereas those shoals feeding in mid-afternoon contained more spent/spent-inactive individuals. The data are too few to form any conclusion on what this pattern should be. It is possible that, because peak pilchard and anchovy spawning occurs at night (O'Toole

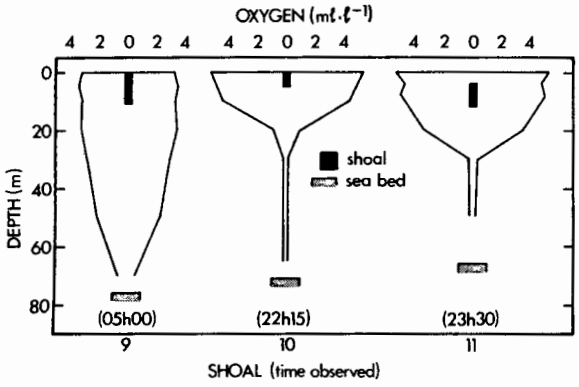

Fig. 10: Vertical distribution of oxygen concentration and pelagic fish shoals, April 1974

1977), fish active in spawning will feed mainly from midday to sunset to conserve energy and to avoid devouring their own eggs.

Good correlation has been shown between the plankton environment and the stomach contents of the South African pilchard (Davies 1957) and of the South West African pilchard and anchovy (King and Macleod 1976). The same has been shown for the Californian pilchard (Anon. 1952) and for the Japanese sardine, *S. melanosticta* (Yoneda and Yoshida 1955). Davies (*op. cit.*), Matthews (1960), Stander and Le Roux (1968) and King and Macleod (*op. cit.*) have recorded the same genera and similar species of diatoms, dinoflagellates, tintinnids and radiolarians from stomachs of South African and South West African pilchard and anchovy as recorded here (Table III). It is therefore assumed to be valid here to suggest that feeding took place from the prevalent plankton environment in which the fish were found, though detailed stomach analyses could not be carried out.

The variation between 665×10^3 and $2\,222 \times 10^3$ cells·ℓ^{-1} in the phytoplankton standing crop at its average maximum depths (5 m) for the survey in both years corresponds with the $643 \times 10^3 - 3\,552 \times 10^3$ cells·ℓ^{-1} found by Kollmer (1963). Figures 3 and 4 show that the uppermost parts of most shoals were located just below the maximum phytoplankton levels. Some shoals, however, extended higher than this maximum.

Diatoms were not only the most abundant group (93,5 per cent) in the environmental phytoplankton crop, but were also dominant in number of species (Table III and Appendix). *Thalassiosira decipiens,* the most important diatom species, constituted 42,1 per cent of the phytoplankton present and was most abundant in the vicinity of Shoals 3—8.

Delphineis karstenii, a more inshore species, was also important, representing 21,1 per cent of the phytoplankton, with its greatest concentration at Shoals 1 and 2, close to the coast, and Shoal 9 (Table II and Fig. 1). *Chaetoceros* spp., which constituted 13,6 per cent of the phytoplankton made their highest contribution at Shoals 7—11. Other diatom species, such as *Asterionella japonica, Nitzschia* spp., *Bacteriastrum delicatulum* and the rest of the diatoms, together contributed some 17 per cent to the phytoplankton present at fish shoal positions.

Other groups constituted 6,5 per cent of phytoplankton present, of which over half were dinoflagellates (3,8 per cent). Species such as the large *Noctiluca scintillans* (diameter 200—1 200 μm) and the very small *Gymnodinium albulum* (<9 μm) were the most common dinoflagellates, especially at Shoals 10 and 11 (Table II). Blue-green algae including *Oscillatoria thiebautii* and some unidentified species made up 1,9 per cent of the phytoplankton present and were most evident at Shoal 6. Unidentified flagellates (usually very small) and the rest of the other groups (tintinnids, radiolarians, foraminiferans, silicoflagellates and coccolithophorids) together contributed about 1 per cent to the environmental phytoplankton.

Fish with significantly greater stomach masses are considered to have been actively feeding just prior to capture. Thus, the anchovy shoal caught at 19h00 is believed to have been feeding during the late afternoon, whereas the shoals caught in the early morning probably did not feed later than the previous midnight. The pilchard shoals are also considered to have been feeding during the afternoon and evening.

The shoals observed here were recorded closer to the surface during the evening and night (Shoals 2—4 and 9—11). During daylight shoals were found further away from the surface than at night (Fig. 4). Each shoal was observed only once on the day of sampling, but a circadian upward and downward migration is assumed from the uppermost depths of the shoals relative to the surface and time of day or night. Agenbag (1973) found that pelagic fish in South West Africa move deeper during the day to a maximum depth at midday or thereabout, then progressively rise to a position at or close to the surface at night. The South West African anchovy is mostly found in open, diffuse layers at or near the surface at night and in more closely packed shoals near the bottom in daytime. Pilchard do not show such a clear pattern. They are generally found in dense shoals at various distances from the surface in

the upper 50 m (R.A.C. personal observation).

There is little evidence of hydrological stimulation for vertical migration or feeding activity. The gradients of temperature around the shoals, and between the surface and any part of the shoals, were less than 1°C over differences of 10—40 m depth. The average temperature range per 10 m depth for thermoclines in South West African waters between 21 and 24°S is 2,2°C in autumn and 1,5°C in winter (Du Plessis 1967). It is clear, therefore, that, during the present study, the waters were well mixed with no strong thermoclines in either autumn or winter. The winter shoals 10 and 11 kept well above the very weak thermoclines, whereas all the other shoals extended deeper in the absence of any thermoclines.

Sea surface temperature associated with Shoals 1—8 (June 1973) ranged from 13,6 to 14,5°C, and for Shoals 9—11 (April 1974) from 16,5 to 17,6°C (Tables IV and V). Shoals 1—8 were in direct contact with subsurface temperatures of 13,2—14,4°C and Shoals 9—11 with temperatures of 16,4—17,6°C. Matthews (1960) reported that average surface temperatures in the main South West African fishing area varied from 12,3 to 14,2°C during winter and from 14,6 to 17,2°C in autumn. De Vos and Visser (1972) reported that pelagic fish were mainly present at surface temperatures below 15,5°C though occasionally as high as 17°C. Agenbag (1980) found that his winter distribution of fish shoals occurred predominantly in waters cooler than 15°C.

Strong oxyclines are distinguishable only at Shoals 10 and 11 where very weak thermoclines are also evident. In these two instances the shoals occurred in the high oxygen concentration above the thermoclines. In fact all the shoals were present in waters of high dissolved oxygen concentration whether it was limited by thermocline formation or penetrated as deep as 60 m. Surface oxygen at Shoals 1—8 varied between 2,85 and 4,91 $m\ell \cdot \ell^{-1}$ and from 3,23 to 5,33 $m\ell \cdot \ell^{-1}$ at Shoals 9—11 (Tables IV and V). This is in general agreement with the findings of De Vos and Visser (1972), who reported that pelagic fish in South West Africa were mainly found associated with a surface oxygen content of 3,5 $m\ell \cdot \ell^{-1}$ or greater. They reported that the highest frequency of catches (90 per cent) was in a surface oxygen concentration of 4 $m\ell \cdot \ell^{-1}$.

This contribution to the shoal ecology of the pilchard and anchovy off South West Africa represents only a few shoals within two limited areas observed for but a short time each. More observations are needed over a longer period to clarify the question of how shoals of these commercially important species behave in response to promptings of their diet and environmental stimuli.

ACKNOWLEDGEMENTS

We wish to thank the editor for the care and diligence with which he rearranged the report into a logical sequence. Messrs A.J. Boyd and B.B.S. Tromp are gratefully acknowledged for critically reading the report and for making useful suggestions for improvement.

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APPENDIX

Phytoplankton species present at fish shoal positions

BLUE-GREEN ALGAE
Oscillatoria thiebautii

GREEN ALGAE
Trochiscia brachiolata

EUGLENOIDS
Eutreptiella sp.

FLAGELLATES
Unidentified spp.

DIATOMS
Actinocyclus octonarius
Actinoptychus senarius
A. splendens
Asterionella japonica
Auliscus sp.
Bacteriastrum delicatulum
Biddulphia longicruris
B. mobiliensis
Cerataulina pelagica
Chaetoceros affinis
C. compressus
C. constrictus
C. convolutus
C. costatus
C. debilis
C. decipiens
C. diademus
C. didymus
C. lorenzianus
C. radicans
C. rostratus
C. socialis
Corethron criophilum
Coscinodiscus centralis
C. gigas
C. lineatus
C. radiatus
C. subtilis
Dactyliosolen mediterraneus
Delphineis karstenii
(= Fragilaria karstenii)
Eucampia zoodiacus
Lauderia annulata
Leptocylindrus danicus
Melosira imbiqua
Navicula corymbosa
Nitzschia closterium
N. delicatissima
N. longissima
N. pungens
N. seriata
Paralia sulcata
Plagiogramma vanheurckii
Pleurosigma directum
P. normanni
Pseudoeunotia doliolus
Rhizosolenia alata
R. delicatula
R. fragillissima
R. imbricata
R. setigera
R. robusta
R. stolterfothii
Stephanopyxis turris
Thalassionema nitzschioides
Thalassiosira aestivalis
T. decipiens
T. eccentrica
T. polychorda
Thalassiothrix antarctica
T. delicatula
T. frauenfeldii
T. heteromorpha
Tropidoneis elegans

SILICOFLAGELLATES
Dictyocha octonaria
Mesocena polymorpha f. *octonaria*

COCCOLITHOPHORIDS
Calyptrosphaera quadridentata

DINOFLAGELLATES
Amphidinium sp.
Ceratium azoricum
C. candelabrum
C. furca
C. fusus
Cochlodinium adriaticum
Dinophysis fortii
D. rotundata
D. sphaerica
Diplopsalis lenticula
Entomosigma peridinioides
Gonyaulax minuta
G. tamarensis
Gymnodinium albulum
G. galatheanum
G. lohmanni
G. uberrimum
Gyrodinium fulvum
Noctiluca scintillans
Peridinium breve
P. conicum
P. crassipes
P. depressum
P. diabolus
P. globulus
P. inconspicuum
P. leonis
P. pellucidum
P. solidicorne
P. steinii
P. triquetrum
P. tristylum
P. trochoideum
Prorocentrum micans
Pyrophacus horologium

FORAMINIFERA
Globigerina bulloides
Globoquadrina dutertrei
Globorotalia menardii
Hastigerina pelagica
Lagena sp.
Orbulina universa

RADIOLARIA
Aulosphaera sp.
Challengeron xiphidon
Dictyophimus brandtii
Lithomelissa sp.
Phormacantha hystrix
Sticholonche zanclea

TINTINNIDS
Acanthostomella sp.
Amphorellopsis sp.
Codonellopsis contracta
C. tuberculata
Dadayiella jörgensenii
Dictyocysta speciosa
Eutintinnus pectinus
Helicostomella subulata
Metacylis jörgensenii
Parundella attenuata
P. lohmanni
Protorhabdonella curta
Rhabdonella conica
R. hensenii
R. spiralis
Salpingella decurtata
Tintinnopsis sp.

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An environmental basin model for west coast pelagic fish distribution

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Key words: Temperature, shoal distributions, environmental basin model, pilchard, anchovy, Benguela.

Palabras clave: Temperatura, distribución de cardúmenes, hábitat ambiental, sardina, anchoa, Benguela.

SUMMARY: Surface temperatures at 20 miles off shore between Cape Town and Cape Frio were used to construct an environmental basin model for pilchard and anchovy. Favourable temperatures were selected to correspond to areas of higher anchovy and pilchard concentrations off South West Africa in Summer and Winter as evidenced by fish shoal distributions. Deviations from these temperatures define the environmental basins. The resulting limits of fish shoal distributions agree with those found off South West Africa and the Cape. A small area favourable for occupation by anchovy is indicated to exist between the Orange River and Lüderitz in both seasons but a major environmental barrier for pilchard is evident between 33° S and 24° S in the summer spawning season. Analysis of shoal depth frequency compared to temperatures confirms the preferred temperature range of 13-18°C.

RESUMEN: UN MODELO DE HÁBITAT MEDIOAMBIENTAL DE LA DISTRIBUCIÓN DE PECES PELÁGICOS EN LA COSTA DE ÁFRICA SUDOCCIDENTAL. — Se utilizaron temperaturas superficiales a 20 millas de la costa, entre Cape Town y Cape Frio, para construir un modelo del hábitat medioambiental de la sardina y la anchoa. Se seleccionaron temperaturas favorables correspondientes a las áreas de más altas concentraciones de anchoa y sardina en África del Sudoeste, tanto en verano como en invierno, como evidencia la distribución de cardúmenes. Las desviaciones de estas temperaturas definen el hábitat medioambiental. Los límites que se obtienen para la distribución de los cardúmenes de peces concuerdan con los encontrados en África del Sudoeste y en el Cabo. Se indica la existencia de una pequeña área favorable para su ocupación por la anchoa, entre el río Orange y Lüderitz, en ambas estaciones, pero es evidente la existencia de una potente barrera medioambiental para la sardina durante la estación de freza estival, entre 33° S y 24° S. El análisis de las frecuencias de profundidades de los cardúmenes comparadas con las temperaturas, confirma que el rango de temperaturas preferidas es el de 13-18 C.

INTRODUCTION

Soon after the inception of pelagic fishing industries at Walvis Bay and the Cape, it was noted that two apparently separate populations of pilchard occurred in these regions (NEWMAN, 1970). Later a similar separation was observed for anchovy. A possible explanation for this feature is proposed

based on the "environmental basin" idea as conceived by Alec MacCall of the Southwest Fisheries Center in California. The present study is an extension of an earlier poster paper by BOYD and CRUICKSHANK (1983). It includes information on shoal occurrence in relation to subsurface temperatures.

METHOD

Average surface temperatures at 20 miles off shore between Cape Town and Cape Frio (BOYD, 1983) were used to construct environmental basin models for pilchard and anchovy. Favourable temperatures were selected to correspond to areas of higher anchovy and pilchard concentrations off South

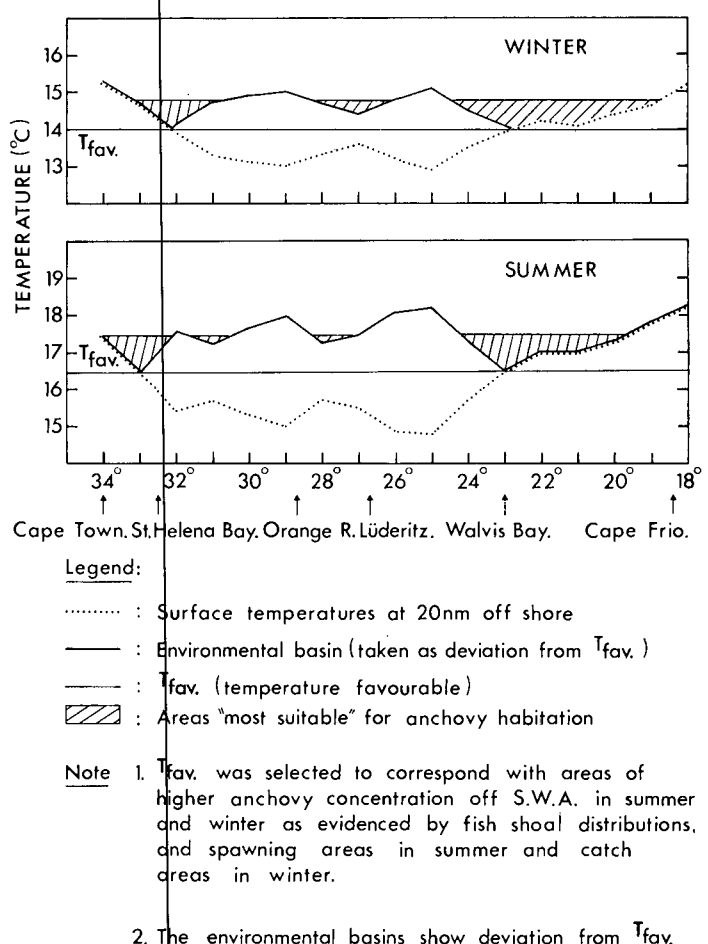
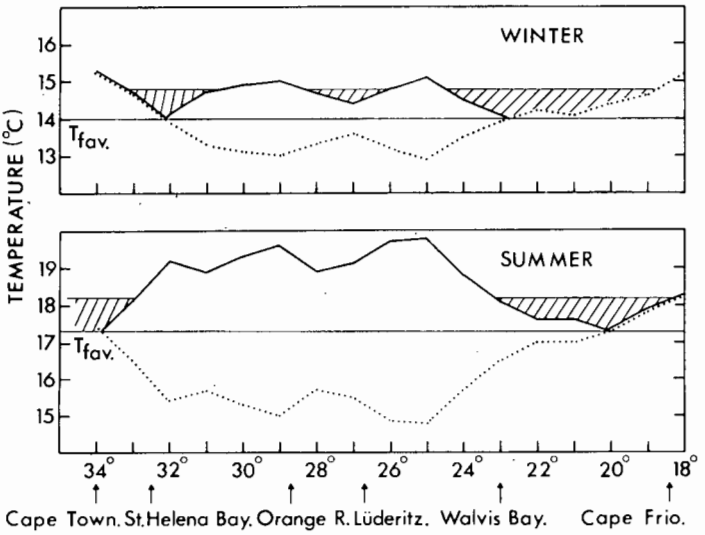


FIG. 1. — «Environmental basins» for anchovy based on West Coast temperatures.

West Africa in summer and winter as evidenced by fish shoal distributions, spawning and catch areas. The pilchard spawning area extends beyond 20 nautical miles off shore but anchovy spawn mainly within 20 nautical miles of the coast (CRUICKSHANK, 1983; LE CLUS, 1983). Hence, a cooler favourable temperature ($T_{fav.}$) has been selected for the spawning anchovy in comparison to pilchard. Deviations from these favourable temperatures define the environmental basins shown in figures 1 and 2.

A study of pelagic shoal distribution and environmental parameters was carried out from October 1978 to April 1983 (CRUICKSHANK, 1983). The data on temperature was analysed in terms of depth distribution of fish shoals



Legend:

..... : Surface temperatures at 20nm off shore

——— : Environmental basin (taken as deviation from $T_{fav.}$)

——— : $T_{fav.}$ (temperature favourable)

▨ : Areas "most suitable" for pilchard habitation

Note 1. $T_{fav.}$ was selected to correspond with areas of higher pilchard concentration off S.W.A. in summer and winter as evidenced by fish shoal distributions, and spawning areas in summer and catch areas in winter.

2. The environmental basins show deviation from $T_{fav.}$

FIG. 2. — «Environmental basins» for pilchard based on West Coast Temperatures.

and associated temperatures which were obtained by direct measurement relative to specific shoals. Data from indirect comparison between distribution of shoal groups and overall temperature distribution are also incorporated. Except for the basin model, "temperature" refers to temperature recorded at depths of shoals and thus includes surface temperatures.

RESULTS

Figures 3-6 illustrate a trend in anchovy and pilchard to concentrate in some areas more than others. The seasonal limits of fish shoal distributions (Figs. 3-6) agree reasonably with those found off South West Africa and the Cape when the "basins" (Figs. 1 & 2) have been filled to appropriate levels.

By accepting the same favourable temperature (14°C) for pilchard and anchovy in winter, their proposed resultant distributions are the same.

In summer, however, the warmer temperatures accepted for pilchard places their basins further northward off SWA and more "overflowing" towards the Cape south coast than anchovy. This "overflow" round the Cape in summer is apparent for both species though, and is in general agreement with the results of CRAWFORD (1980, 1982 a & b).

Off SWA a small area favourable for occupation by anchovy is indicated to exist between the Orange River and Lüderitz. Acoustic surveys have found this true in early winter and in some summers. However, a major environmental barrier for pilchard is evident between 33° S and 24° S in the summer spawning season.

Individual seasons may show variations of the favourable temperature and different shoal distributions. For example, shoals of anchovy juveniles were detected off the Orange River in 1979, 1982 and 1983 during later summer months but not until autumn and winter in 1980 and 1981. The years 1978 and 1983 showed most evidence of shoals in this area. Highest commercial catch totals of pilchard were made between 22° S and 22° 30′ S latitudes in winter 1981, but in 1982 most shoals caught were found between 19° 30′ S and 21° S latitudes. Both these areas fall within the appropriate basins.

The percentage frequency of pelagic shoal occurrence relative to temperatures for summer and winter are presented in Figure 7. Figure 8 shows the relationship between depth at which shoal groups occurred and the associated temperatures. There is a marked decline in numbers of shoals observed when temperatures drop below 13°C. This is true throughout the year despite seasonal changes in favourable surface temperatures. This supports the validity in choice of $T_{fav.}$ for the basin model. Most frequent occurrence of shoals deeper than 30 m is associated with penetration of warm temperatures to deeper depths (Fig. 8).

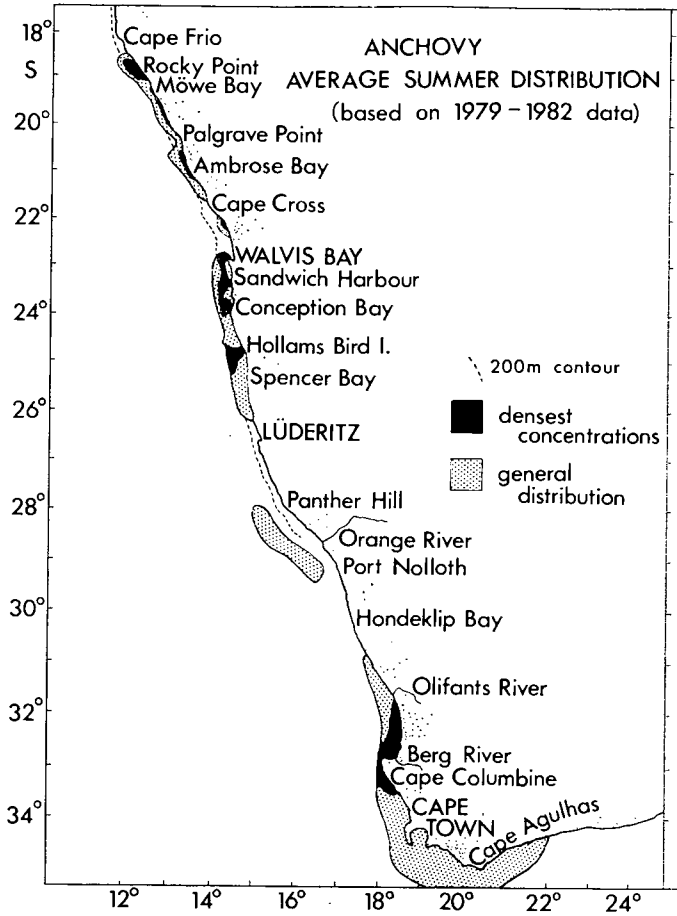


FIG. 3. — Average summer distribution of anchovy in the south-east Atlantic.

FIG. 4. — Overall winter distribution of anchovy in the south-east Atlantic.

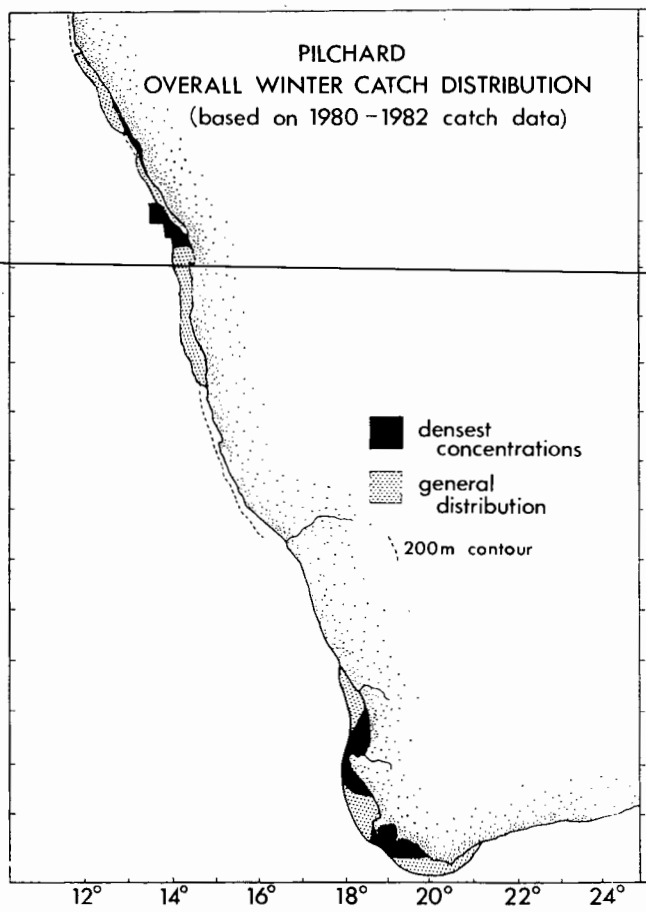


FIG. 6. — Overall winter distribution of pilchard in the south-east Atlantic.

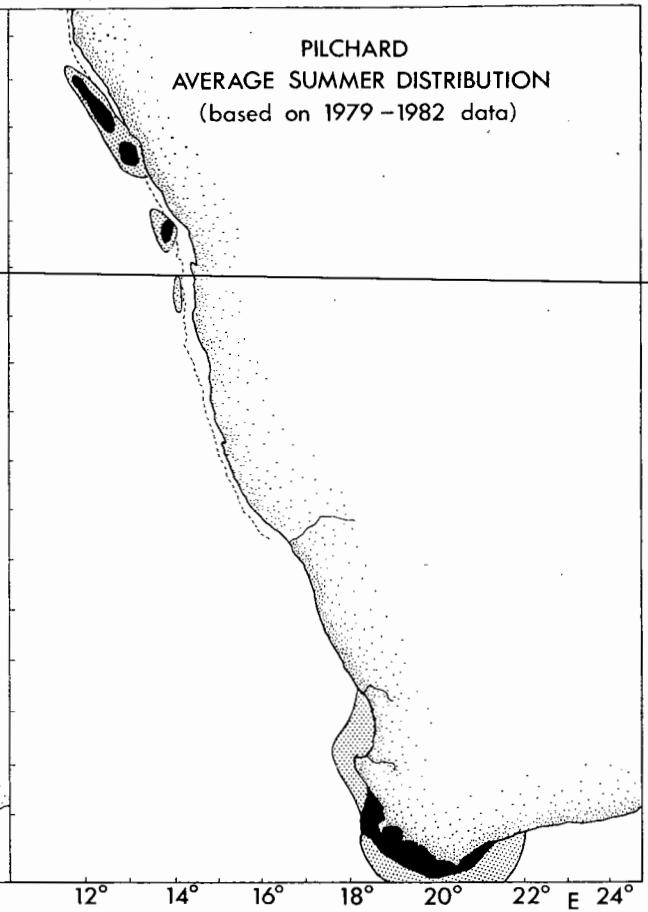


FIG. 5. — Average summer distribution of pilchard in the south-east Atlantic.

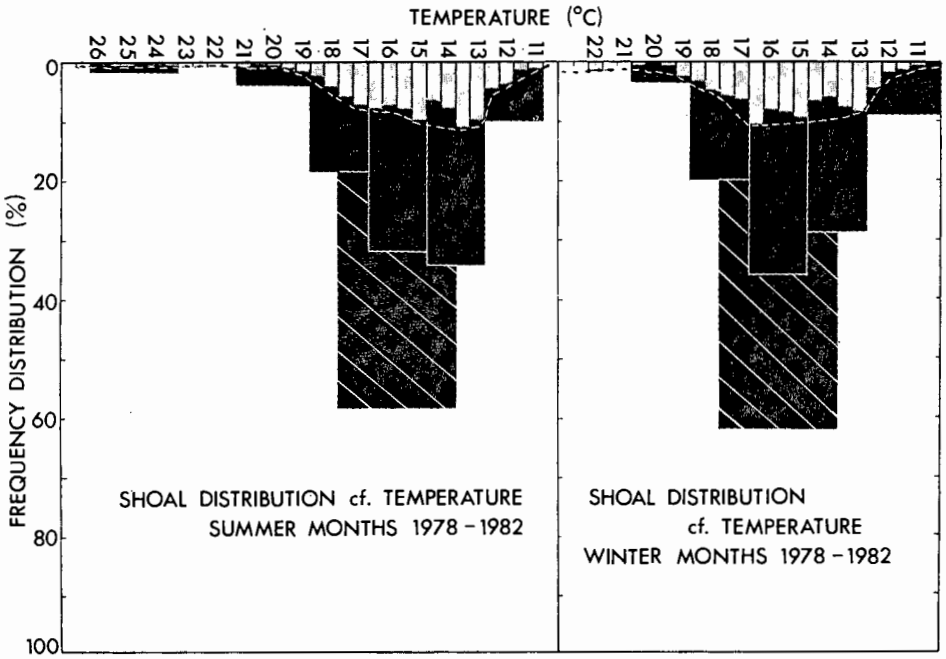


FIG. 7. — Shoal frequency compared to temperature, plotted in 0.5°C (light shading), and 2°C (dark shading) intervals. Finally the percentage frequency of shoals between 14°C and 17.5°C (stripped shading) is shown.

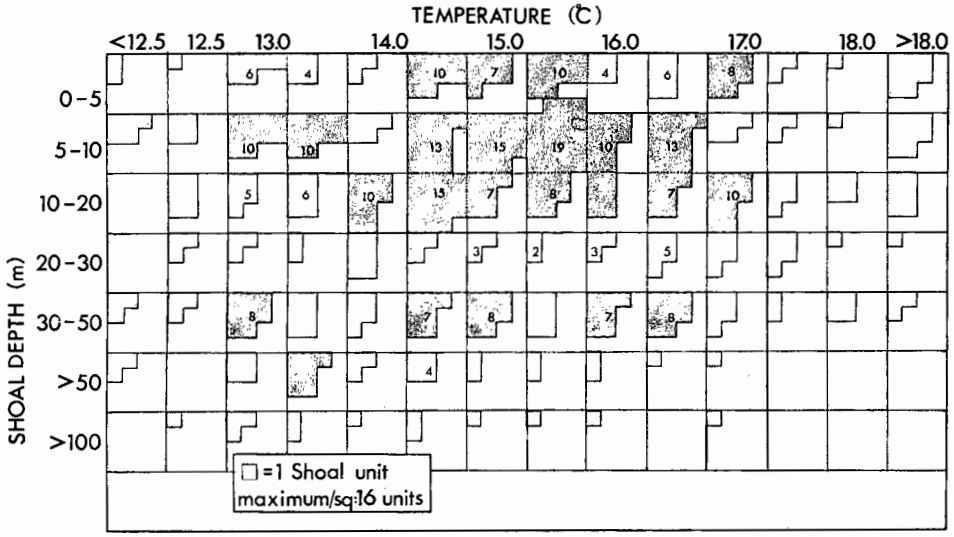


FIG. 8. — Shoal distribution compared to depth and subsurface temperature. Each «unit» represents a shoal group recorded at a given depth and temperature. Each depth/temperature square can contain 16 shoal units. Squares containing 7 or more units are darkly shaded. Only the 15.5°C/5-10 m square was filled and exceeded with 19 of the 447 shoal groups recorded.

DISCUSSION

Average longshore temperature trends and temperature ranges with depth bear a relationship to pelagic fish shoal distributions in accordance with the proposed environmental basin model.

The selected favourable temperatures for pilchard and anchovy within the range 13° to 18°C are in reasonable agreement with previous authors. DAVIES (1956 & 1957) selected 15°C as optimal for pilchard off South Africa with main spawning between 14° and 16°C in a range 12° to 22°C. STANDER (1963) distinguished a cold and a warm period for spawning with the former varying between 12° and 15°C and the latter covering a wide range of temperatures above 15°C. MATTEWS (1960) reported ranges of 12.3° to 14.2°C in winter and 14.6° to 17.2°C in autumn for surface temperatures associated with the main commercial fishing off South West Africa. DE VOS and VISSER (1972) reported that pelagic fish off South West Africa predominated below 15.5°C but were found in temperatures of up to 17°C. AGENBAG (1980) found that his winter distribution of shoals occurred mostly in waters cooler than 15°C whereas in summer they were in temperatures more than 15°C and even in excess of 17°C sometimes. KRUGER and CRUICKSHANK (1982) reported shoals in winter at subsurface temperatures from 12.5°C to surface temperatures between 14° and 17°C. Most of these authors drew their conclusions from indirect comparison between distributions of temperature and fish shoals whereas KRUGER and CRUICKSHANK (*op. cit.*) used direct measurements for specific shoals.

This report deals with data from both methods in support of long-term averages in temperature and shoal distribution. It shows that two largely separate areas are suitable for the occurrence of pilchard and anchovy shoals off the west coast of southern Africa. There is also a restricted area in between which is marginally suitable for anchovy. It shows too that, regardless of depth, over 60 % of pelagic fish shoals were recorded in waters between 13°C and 18°C in both summer and winter.

ACKNOWLEDGEMENTS

Our thanks to Mrs R. Mackay and Mr R. Cooper and their technical staff for considerable assistance in collection and processing of the data.

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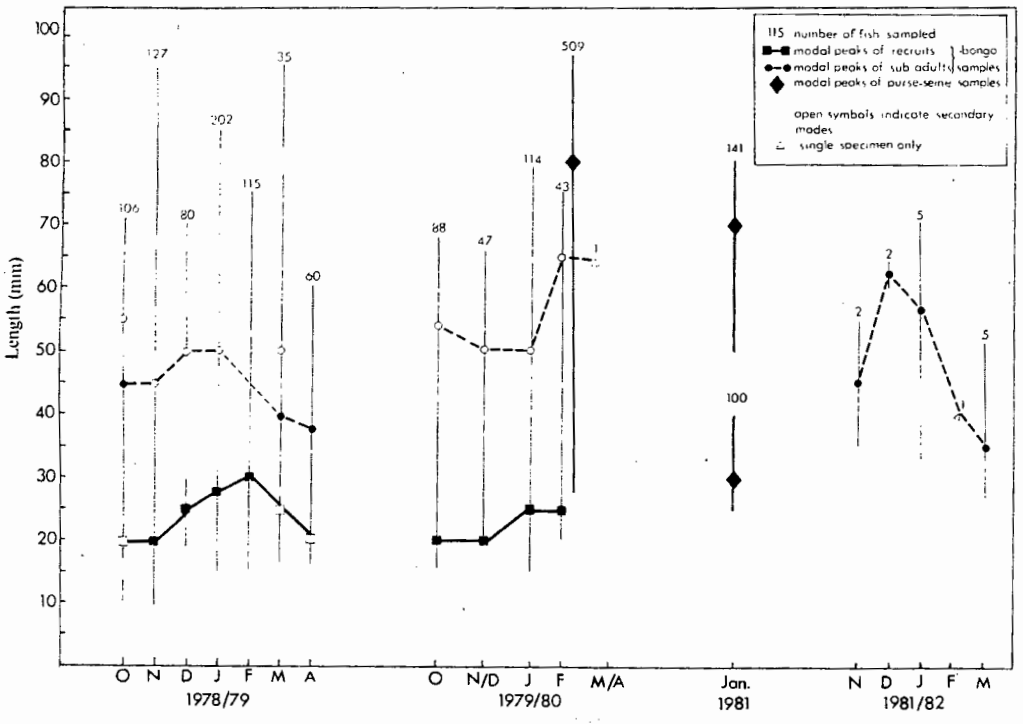

Fig. 2. Monthly length range (L_t) and modal peaks obtained each season from bongo net samples plus some samples obtained from purse-seine nets.

The concentration of lanternfish over the outer shelf and canyon areas and associated differences of species diversity and density between Cape waters and different regions off the west coast raise interesting ecological questions.

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An Environmental Basin Model for West Coast Pelagic Fish Distribution

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Soon after pelagic fishing industries were established at Walvis Bay and in the Cape Province, it was noted that two apparently separate populations of pilchard occurred in these regions.[1] Later, a similar separation was observed for anchovy. A possible explanation for this behaviour is proposed based on the 'environmental basin' idea as conceived by A. MacCall of the South West Fisheries Centre in California (personal communication).

Surface temperatures 20 miles offshore between Cape Town and Cape Frio[2] were used to construct environmental basin models for pilchard and anchovy. Favourable temperatures were selected to correspond to regions of relatively high anchovy and pilchard concentrations off Namibia in summer and winter as evidenced by fish shoal distributions, spawning and catch areas. The pilchard spawning area extends beyond 20 nautical miles offshore, whereas anchovy spawn mainly within 20 nautical miles of the coast.[3,4] Hence, a lower temperature has been selected as favouring the spawning of anchovy compared with that for pilchard. Deviations from these favourable temperatures (T_{fav}) define the environmental basins shown in Fig. 1. The resulting seasonal limits of fish shoal distributions (Figs 2 and 3) are in reasonable agreement with those found by hydroacoustic surveys and from catch statistics off Namibia and the Cape when the 'basins' have been filled to appropriate levels.

By accepting the same favourable temperature (14°C) for pilchard and anchovy in winter, their theoretical resultant distributions are the same. In summer, however, the higher temperatures accepted for pilchard place their basins further northwards off Namibia and extending more towards the Cape south coast than for anchovy. This spread of distribution round the Cape in summer is apparent for both species, and is in general agreement with the results of Crawford.[5-7]

Off Namibia a small area favourable for occupation by anchovy is indicated near the Orange river mouth and Lüderitz. Acoustic surveys have found this to be the case in early winter and in some summers. However, a major environmental barrier for pilchard is evident between 33°S and 24°S in the summer spawning season. Individual seasons may show the favourable temperature to vary and different shoal distributions. For example, shoals of anchovy juveniles were detected off the Orange river mouth in 1979 and 1982 during late summer months but not until autumn and winter in 1980 and 1981. The highest commercial catches of pilchard were taken between 22°S and 22°30′S in winter 1981 but in 1982 most shoals were found between 19°30′S and 21°S. However, both areas fall within the ap-

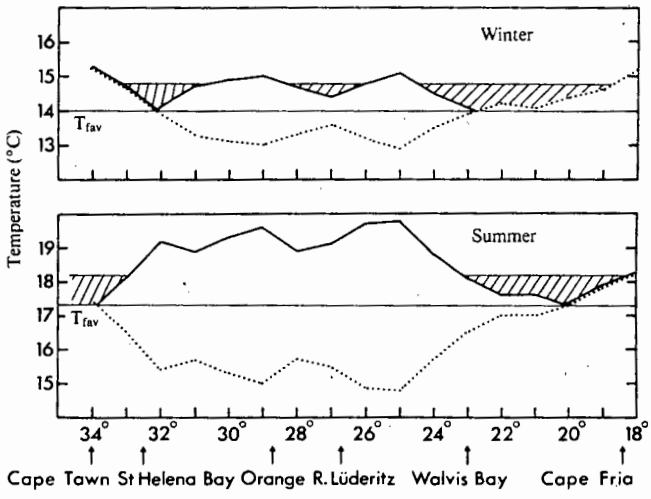

Fig. 1. An environmental basin model for pilchard along the west coast of Southern Africa using optimal temperatures.

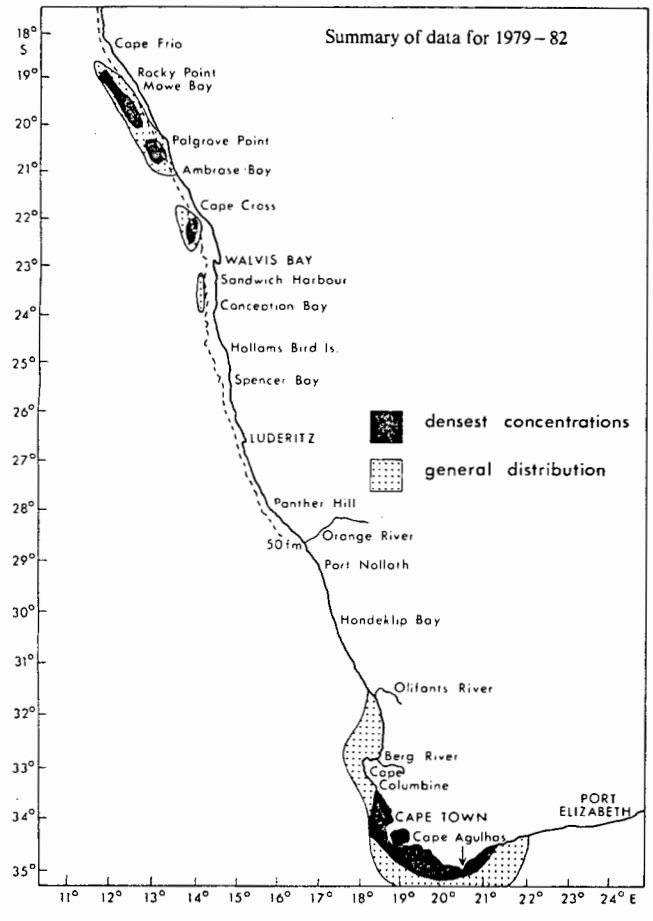

Fig. 2. Average summer distributions of pilchard along the west coast of Southern Africa.

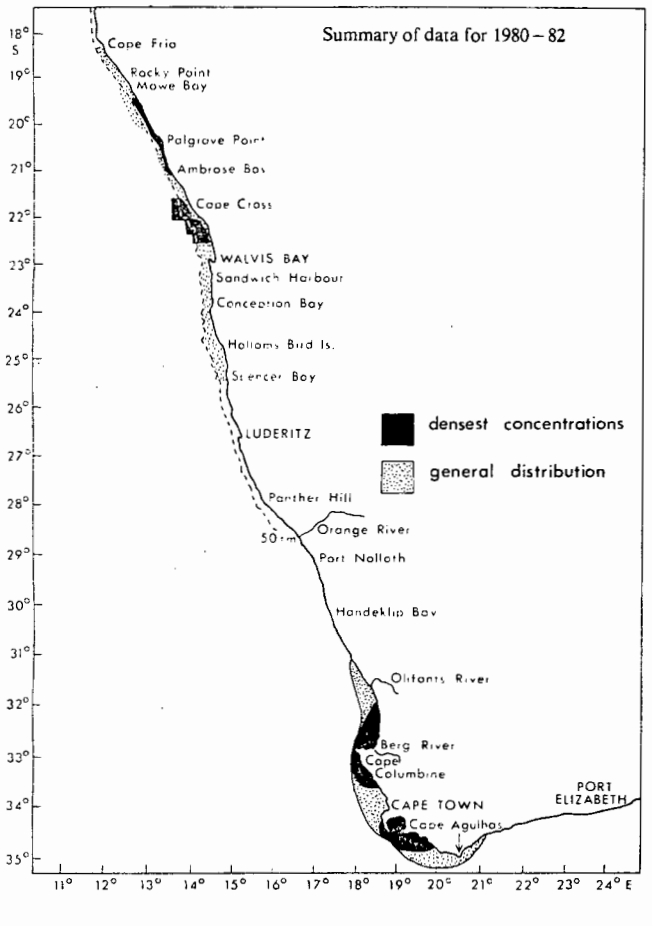

Fig. 3. Average winter distributions of pilchard along the west coast of Southern Africa.

propriate basins. We therefore conclude that average longshore temperatures and fish shoal distributions bear a relationship in accordance with the proposed environmental basin model.

1. Newman G.G. (1970). *Investl Rep. Div. Sea fish S. Afr.* **86**, 1 – 6.
2. Boyd A.J. See p. 146.
3. Cruickshank R.A. See p. 147.
4. Le Clus F. See p. 143.
5. Crawford R.J.M. (1980). *J. Fish Biol.* **16**, 649 – 664.
6. Crawford R.J.M. (1982). *Fish. Bull. S. Afr.* **14**, 1 – 46.
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Southern Ocean

The Southern Ocean Islands Survey Programme

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In October 1979, the Sea Fisheries Branch (now the Sea Fisheries Research Institute) assumed responsibility for the Southern Ocean Islands Survey Programme. The primary objective of this programme was: 'To improve existing knowledge on the relative abundance and distribution of pelagic organisms around sub-Antarctic islands, particularly as affecting their importance to island-based predators.' To date, combined hydroacoustic/hydrological surveys have been undertaken of the Gough (40°20′S, 09°54′W) and Prince Edward (46°45′S, 37°55′E approximately) island regions. The results offer both a preliminary assessment of micronekton abundance and of survey techniques.

Acoustic reflectivity in the survey areas was low, indicating an associated low micronekton abundance.[1,2] Poor net catches supported this result. Low levels of production were also encountered in near-island waters.[3,4] The predominant water character of the two survey regions was different, however. The Gough Island area appeared to be affected by the intrusion of sub-tropical water from the north. Near-island waters were subject to both vertical and horizontal mixing while also being influenced by topography.[3] At Prince Edward, waters were predominantly sub-Antarctic, but there was evidence to suggest that sporadic intrusions of Antarctic surface water affected the hydrology.[4] In combination with a proposed 'island-mass effect',[4,5] this process could influence near-island productivity.[4]

A scarcity of acoustic targets precluded a successful marriage of acoustic and net catch results. As a result, reliable estimates of specific abundance were not possible. Nevertheless, catch data were used to index relative faunal abundance.[1,2] Comparisons of catch data showed interesting variations between the two survey areas. Both regions exhibited species cosmopolitan to the sub-Antarctic as a whole. Each region also contained species endemic to their respective faunal provinces. The balance of species reflected prevalent hydrological conditions encountered during each survey.[1,2]

In view of the vast island-based predator populations at both localities, a scarcity of potential dietary organisms was unexpected. At Prince Edward, results could be attributed to seasonal variation in micronekton abundance. The survey took place during winter when low abundance is characteristic of sub-Antarctic waters.[6] The presence of relatively few island-based predators supports this observation.[1] At Gough, the survey took place during early summer and a seasonal low micronekton abundance was unlikely. Therefore, it could be attributed to only the associated low productivity and nutrient salt availability observed and consistently reported from the region.[3,7,8] The suggestion is made that, at Gough, predators either feed close inshore or alternatively forage farther afield in their search for food. In lieu of further evidence, a high incidence of more mobile bird species on Gough[9] is consistent with the latter alternative. The situation was somewhat different at Prince Edward and a high penguin population[10] intimates that the majority of island-based predators forage close inshore. The close proximity of the Antarctic Polar Front offers an ideal locality for enhanced productivity and hence food. It is suggested that predators on Prince Edward may supplement low insular food availability by periodic excursions to the frontal region.

Of the more common micronekton collected, *Parathemisto gaudichaudii, Euphausia vallentini* and *Nauticaris marionensis* have been found in the stomachs of predators. *Thysanoessa vicina* and *Thysanoessa macrura* have also been implicated as dietary items.[11] They were not encountered during the present surveys, probably as a result of the nets used.

Results highlight the fact that estimates of pelagic abundance are ex-